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SUPPLEMENTARY LIFT FOR AIR CUSHIONED VEHICLES

(PERFORMANCE ANALYSIS)

Volume III of III

Task 9R99-01-005-03
Contract DA44-177-TC-708

June 1962

prepared by:

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The principle of increasing the efficiency of Air Cushion Vehicles (ACV) by making use of the aerodynamic lift available at forward speeds has been investigated in this instance for vehicles oriented to the command and reconnaissance mission and to the off-road logistics mission. The study points up the considerable benefits of utilizing this concept; however, it also illustrates the limitation of the concept, i.e., relatively high speeds are required to gain a significant advantage. The basic wind-tunnel data contained in Volume I and the data analysis contained in Volume II are sufficiently comprehensive to enable a designer to make a preliminary design study of an ACV that would satisfy mission requirements other than those considered in Volume III.

Based on the results of this investigation, it is concluded that any ACV designed for mission requirements which include a significant portion of high-speed operation should be configured to take advantage of aerodynamic off-loading.

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SUPPLEMENTARY LIFT FOR AIR CUSHIONED VEHICLES
VOLUME III OF III. PERFORMANCE ANALYSIS

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PREFACE

This report is an account of the results obtained during a wind tunnel study of supplemental lift for air cushioned vehicles. The study was conducted under contract DA 44-177-TC-708 for the U. S. Army Transportation Research Command (USATRECOM). Mr. William Hinshaw of the USATRECOM served as the Army's technical representative. Responsibility for conducting the study was assigned to the Special Projects Section of the Research Department, Grumman Aircraft Engineering Corporation. Mr. William Aubin is Section Head and Dr. Charles E. Mack,Jr. is Director of Research.

The results of this study are presented in three volumes. Volume I* presents the basic wind tunnel data. Volume II presents the data in parametric form as a function of air mass flow coefficient. In this form the data allow evaluation of the effect of vehicle jet nozzle configuration changes on aerodynamic off-loading (supplemental lift). This volume (Volume III) utilizes the results of the investigation in a performance study of vehicles for the command reconnaissance and logistics missions of the U. S. Army.

The authors gratefully acknowledge the efforts of the Aero-Test Operations Group of Grumman, in particular Mr. Richard Ledesma, in conducting the wind tunnel tests,and Mr. Geoffrey Gardner and Mrs. Freda Cellana for data reduction.

*Available on loan basis from USATRECOM.

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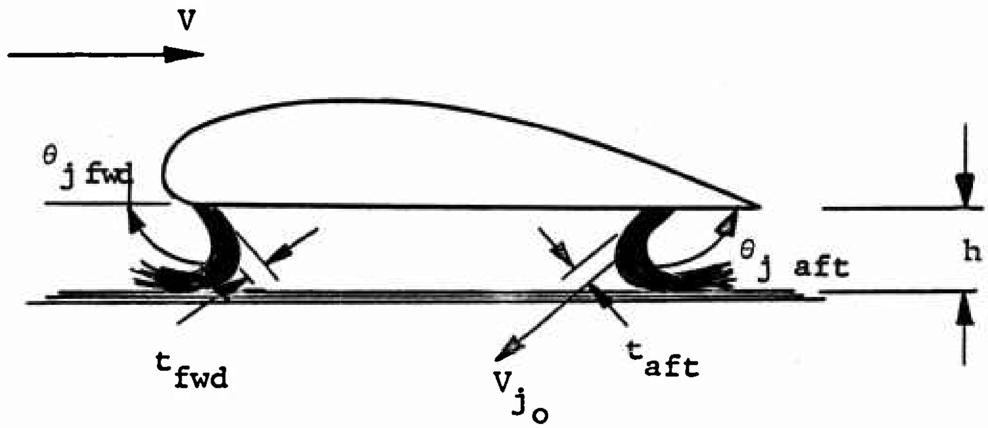
LIST OF SYMBOLS

AR	aspect ratio, $\frac{\text{width}}{\text{length}}$
C	cushion chord (base plus jet), ft
C_D	drag coefficient, $\frac{\text{drag}}{qS}$
C_j	peripheral jet length, ft
C_L	lift coefficient, $\frac{\text{lift}}{qS}$
C_ℓ	rolling moment coefficient, $\frac{\text{rolling moment}}{CqS}$
C_m	pitching moment coefficient, $\frac{\text{pitching moment}}{CqS}$ (moment reference center at 48.8 percent cushion chord)
C_μ	blowing coefficient, $\frac{\dot{m}V_{j_o}}{qS}$
D	drag, lbs
h	height above terrain (ground board), measured to base at moment reference center, in., ft.
$\dot{m}$	mass flow, slugs/sec
P_T	total pressure, psf
q	free stream dynamic pressure, psf
q_{j_o}	jet total pressure above ambient, psf
S	cushion base area (basic configuration, base plus jet) ft^2

S_j	peripheral jet area, ft^2
SHP	shaft horsepower
t_e	thickness of jet, in., ft.
V	free stream velocity, ft/sec
V_{j_o}	velocity of jet at nozzle when expanded to atmospheric pressure, ft/sec
V_j	average jet velocity, ft/sec
$\dot{w}$	weight flow, decimal equivalent of maximum weight flow, lbs/sec
α	angle of attack
Δ	increment
η_D	inlet and ducting efficiency
η_F	fan efficiency
η_I	intake efficiency (inlet q recovery)
η_P	propulsive efficiency
ϕ	angle of roll
θ_j	angle of jet (measured from horizontal)
ρ	free stream density of air



Sign Convention

pitch	-	positive nose up
roll	-	positive right wing down
lift	-	positive up
drag	-	positive aft

All other symbols defined as they appear in the text.

SUMMARY

The results of a wind tunnel study of supplementary lift for air cushioned vehicles (Volumes I and II) were applied to vehicles for the army command reconnaissance and logistics missions outlined in Ref. 1. Aerodynamic off-loading of air cushioned vehicles results in an increase of power available during cruise which can be utilized to increase cruise height above the hover height or to operate during cruise at lower power settings.

The utilization of aerodynamic off-loading greatly increases the mission potential of the air cushioned vehicle. With the configurations in these tests, aerodynamic off-loading was most effective at speeds of 60 miles per hour and above, optimum speed increasing with base loading. At 20 lbs/ft^2 base loading (16.67 lbs/ft^2 wing loading) approximately 100 miles per hour offered the lowest power required. However, efficient hover jet configurations are required so that increased propulsion system weight does not compromise fuel or payload. Variable leading and trailing edge jet nozzles appear to be highly desirable in providing both aerodynamic off-loading for efficient cruise and an optimum hover configuration.

Multiple engine installations also appear to be highly desirable. Because of the dissimilar power requirements between hover and aerodynamically off-loaded cruise at a given height, range at this height can be extended by shutting down some portion of the installed engines (turboprop or turboshaft) and operating the remainder at higher, more efficient, power settings.

INTRODUCTION

The advantages inherent in applying aerodynamic lift to air cushioned vehicles are manifold. The performance of air cushioned vehicles is compromised at higher speeds by the momentum, or ram drag. This is particularly evident where large mass flows of air are involved, such as they are for high base loadings and/or high traversal heights. Ram drag for such configurations severely inhibits maximum speed or leads to large increases in required power above that needed for hover. It thus affects the practicability of air cushioned vehicles by reducing speed, payload and/or range.

Reduction of ram drag can be achieved by decreasing the vehicle weight that has to be supported by the air cushion. This can be achieved practically by aerodynamic off-loading of the air cushion, which is most effective where it is most needed — at high speeds. With respect to configurations with integrated powerplant systems, where the total power is divided as needed between the air cushion and the propulsive system, aerodynamic off-loading of the air cushion not only reduces the ram drag (and over-all drag) by decreasing the mass flow required to maintain the air-cushion, but also increases the gross thrust available for forward propulsion by reducing the power required by the air cushion system. For configurations with independent power plants for the air cushion and propulsive systems, aerodynamic off-loading should reduce total power expenditure and fuel consumption by allowing a reduction of power (or number of engines operating) in the air cushion system.

In order to explore the performance benefits and stability problems associated with aerodynamic off-loading of air cushioned vehicles, we conducted a wind tunnel program in the Grumman 7-by 10-foot low speed wind tunnel. The program employed a semispan reflection plane model that, by means of a variable jet configuration, represented a family of air cushion vehicles.

The model has a flat-bottomed airfoil section derived from the basic Clark Y profile. The ordinates of the Clark Y profile were increased to yield a 16-percent thick airfoil section, the bottom flattened between the 8- and 30-percent chord, the leading edge radius increased and faired in tangentially to the flat bottom at the 8-percent chord, and the trailing edge reflexed 1.73 percent starting at the 89-percent chord.

The "wing" aspect ratio is 0.833. The air cushion base aspect ratio is 1.00 and is formed by a rectangularly shaped peripheral jet which can be varied in both thickness and deflection at the leading and trailing edges.

The basic full scale jet thickness and deflection angle was considered to be 6.0 inches and 90 degrees for the command reconnaissance vehicle and 9.0 inches and 90 degrees for the logistics vehicle. Four other leading edge and trailing edge jet thicknesses (7.5, 9.0, 4.5, and 4.0 inches for the command reconnaissance vehicle and 11.25, 13.5, 6.75, and 4.5 inches for the logistics vehicle) and two other jet deflection angles (120 degrees and 60 degrees for both vehicles) were tested. The wing chord to ground effect base chord varied (in relation to the basic configuration) with jet deflection angle but not with jet thickness. Although the ground effect base area varied because of this procedure (-2.3 to +2.7 percent), it should be appreciated that practical air cushioned vehicles utilizing variable nozzles will suffer a similar change in ground effect base area with jet nozzle variations (Ref. 2) for given external dimensions. In addition three trailing edge configurations with jet flap nozzles of 30-, 45-, and 60-degrees deflection and no structural overlap were tested. Their use increased the ground effect base chord (and area) by 4.1 percent in relation to the basic configuration. Details of the test model are discussed in Volumes I and II.

The basic model (aspect ratio 0.833) was tested at height-size ratios $hC_j/4S$ of 0.156, 0.104, and 0.052. The height-size ratios are increased 2.3 percent for the 120-degree jet configurations and decreased 2.7 percent for the 60-degree jet configurations. These values represent full

scale heights of 4.00, 2.67, and 1.33 feet for the command reconnaissance vehicle. Tests at the height-size ratio of 0.052 also represent the specified full scale height of 2.00 feet for the larger logistics vehicle. These height-size ratios and specified full scale heights fixed the size of the command reconnaissance and logistics vehicles to 30.7- and 46.1-foot wing chords, and 25.6- and 38.4-foot wing spans respectively. Figs. 1 and 2 illustrate possible configurations for these vehicles.

DISCUSSION

The peripheral jet air cushioned vehicle with various leading and trailing edge nozzle configurations was evaluated with respect to the command reconnaissance and logistics missions outlined in Ref. 1. The nozzle configurations are summarized in Appendix II.

The requirements stipulated a command reconnaissance vehicle (CRV) with the following performance:

a) maximum velocity of 100 mph,
b) payload of 750 lbs,
c) mission duration of 4 hours,
d) maximum obstacle capability of 4 feet,

and a logistics vehicle (LV) with the following performance:

a) maximum velocity of 60 mph,
b) payload of 5000 lbs,
c) mission duration of 8 hours,
d) maximum obstacle capability of 2 feet.

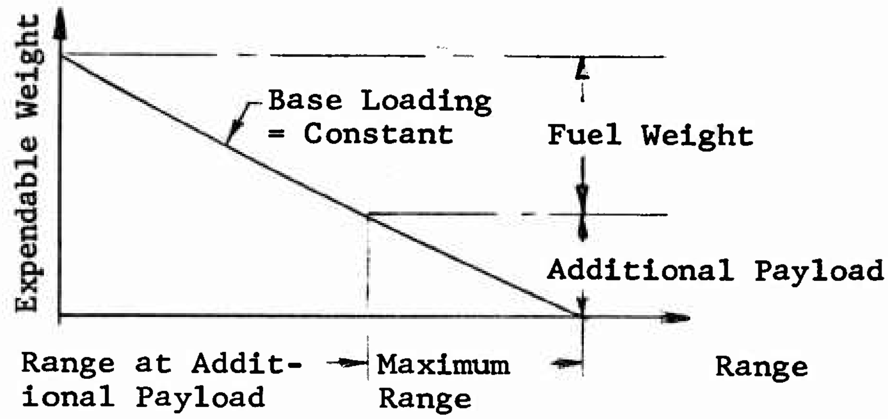
Although range requirements were not stipulated, it was assumed that range should be the product of maximum velocity and endurance. Thus, 400-mile and 480-mile ranges were considered as "requirements" for the CRV and LV respectively. It was also initially assumed that the maximum height capability would be "required" at, or very near, zero speed since it can be foreseen that vehicles of this type can become boxed-in on terrain where there is insufficient room to accelerate to the velocities required for aerodynamic off-loading and increased height capability. However, it soon became evident that the power required for the CRV to hover at maximum height would entail too great an installed powerplant weight which would, first, greatly diminish the allowable fuel weight and second, uneconomically consume the available fuel supply during cruise due to the mismatch of required hover and cruise power. This is essentially similar to VTOL aircraft.

However, unlike VTOL aircraft, the air cushion vehicle can reduce its hover power requirement by hovering at a lower height, and still be capable of translating at a higher height. Thus, for the CRV, height at hover was taken to be 1.33 feet (and for one configuration 2.67 feet) and cruise height was taken to be 1.33 feet, 2.67 feet, and 4.00 feet. For the LV, the height at both hover and cruise was taken to be 2.00 feet.

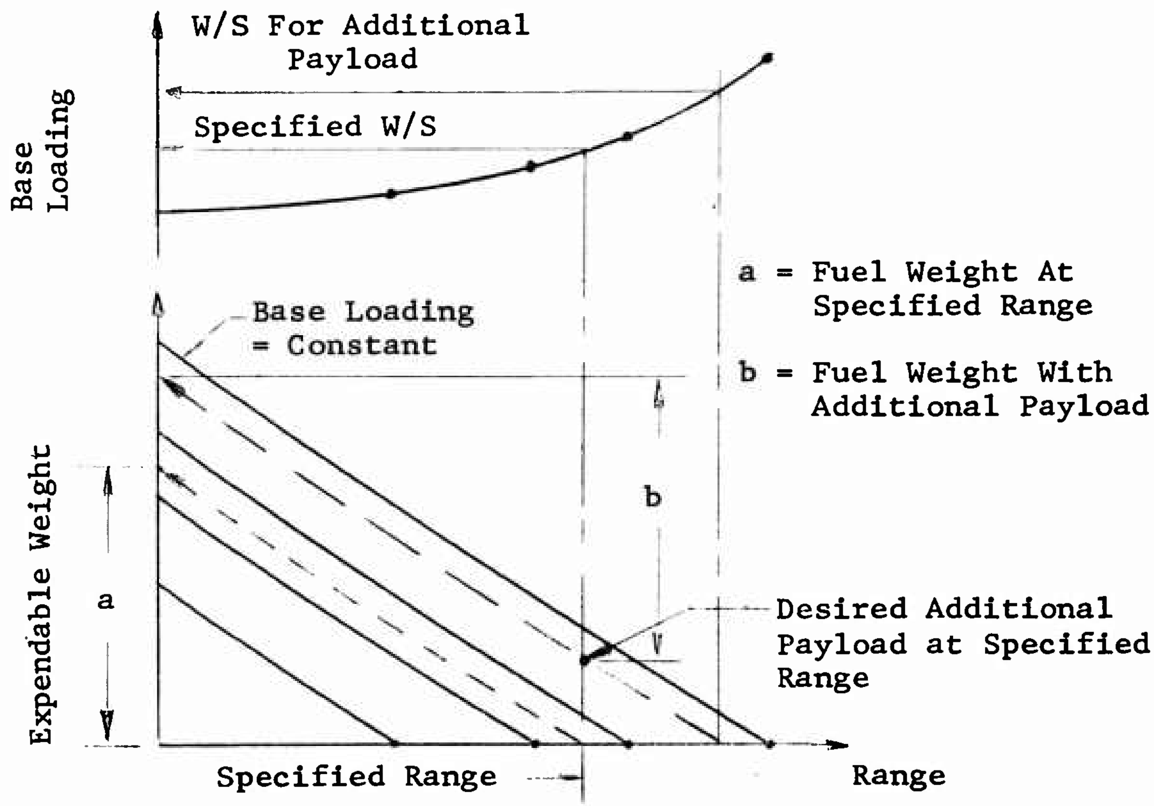
Only integrated powerplant systems, where the power is divided (as required) between the cushion and separate forward propulsion systems, are considered during this investigation. This is in contrast to independent powerplant systems where separate engines power the cushion and forward propulsion systems. Refs. 2, 3, and 4 and numerous in-house design studies have shown that integrated powerplant systems result in the minimum total power installation, minimum propulsive system weight, and maximum flexibility.

Turboprop engines were the only engine types considered during this investigation due to their light specific weight and their future availability in varying power ranges as compared to aircraft weight piston engines. Multiple engine installation of the turboprop engines was considered in order to fully capitalize on the reduced power requirements during cruise. This affords the possibility of shutting down some portion of the installed engines and operating the remaining engines at higher, but more economical, power settings. Due to time limitations, only a multiple-of-two engine installation, with either all or one half the engines operating, was considered.

The configurations were evaluated on the basis of range versus expendable weight for base loadings between 9 and 20 lbs/ft^2. Range was considered more amenable to evaluation than endurance and all comparisons were made with respect to range. Expendable weight can be considered as fuel weight or additional payload above that stipulated in Ref. 1. A sketch of a typical plot is shown below.



The base loading (or gross weight, since the height-size ratio and the specified height fixed the base area of the vehicles, Fig. 3) and expendable weight were determined by the use of the following charts made for each configuration.



The expendable weight/range curves were calculated using a variation of the growth factor equation. A complete development of this equation is presented in Appendix I. The final equation which expresses range as an integral function of weight is

$$\text{Range} = \frac{V}{.737} \int_{0}^{W_{F+FS}} \frac{dW}{SHP_c \times F_{P/S}}$$

where

W_{F+FS} = fuel and fuel system weight

SHP_c = cruise shaft horsepower required

$F_{P/S}$ = ratio of specific fuel consumption at a particular power setting to the specific fuel consumption at military rated power.

The performance analysis was conducted for both the CRV and LV. Some of the engine and vehicle parameters required during this performance analysis are presented in Figs. 4 through 8. The effect of variations in these parameters are discussed later in the text. Fig. 4 presents the structural and equipment weight factor as a function of base loading. Fig. 5 illustrates the variation of specific fuel consumption with power setting. Drag coefficient, presented as C_D versus C_μ, is presented in Figs. 6 and 7 for the symmetrical and unsymmetrical configurations. The assumed variation of propulsive efficiency with forward velocity is presented in Fig. 8. Figs. 9 and 10 illustrate typical values of shaft horsepower required versus velocity for the CRV and LV.

PERFORMANCE OF THE COMMAND RECONNAISSANCE VEHICLE

The performance analysis for the CRV was conducted in two parts. Angularly symmetrical nozzle configurations were analyzed first with the intent of evaluating simple

jet configurations from zero to high speeds. Next, sophisticated jet configurations were evaluated at specified cruise speeds using the powerplant weights of the more efficient angularly symmetrical configuration at hover. These results represent performance benefits that could be gained by utilizing variable deflection and thickness peripheral jet nozzles. The nozzle variables are presented in Appendix II. The first 9 configurations represent vehicles with angularly symmetrical jet nozzles; the next 12 configurations represent the sophisticated cruise jet configurations.

The effect of operating height, jet thickness, jet angle, differential leading and trailing edge jet thickness (constant total jet area), tip jet plus jet flap operation, and tip jet only operation, were evaluated in the analysis utilizing the data of Volumes I and II. Base loadings of 9, 12, 16, and 20 lbs/ft^2 were considered since base loading has a pronounced effect on performance. Low base loadings cause structural weight and parasitic drag to predominate in affecting vehicle performance; high base loadings cause ducting efficiency and fan efficiency (hover horsepower) to predominate. Base loading was used as the basic parameter instead of gross weight to facilitate scaling these data to larger vehicles at the same height-size ratios.

Height

The effect of height was evaluated with configuration (1). The CRV designed to hover and cruise at the specified height of 4.0 feet was unattainable, since the high installed power requirements and resulting propulsion system weight did not permit fuel. (This was true of all 9 configurations when required to hover at 4.0 feet, even though configurations (2) and (4) were theoretically more efficient in hover.) The CRV designed to hover and cruise at 2.67 feet did permit fuel, but its range potential is quite inadequate with respect to the performance requirements. This is evident when it is compared with hover and cruise at 1.33 feet, Fig. 11. Configuration (1) with base loadings greater than 12.3 lbs/ft^2 can achieve the required

range with hover and cruise at 1.33 feet. By increasing the base loading to 20 lbs/ft^2, The expendable weight at zero range is increased from 1750 lbs. to 4080 lbs. This represents as much as a 233-percent increase in payload at short ranges, or an increase in range to 550 miles. With half of the installed engines shut down, maximum range was increased to over 700 miles. Due to the decreased power requirements at cruise speed (as compared to hover) for the higher base loaded vehicle, operating the vehicle with half the engines shut down during cruise permitted the remaining engines to be run at a more economical power setting.

Jet Thickness

The effect of jet thickness (t/h of 0.375, 0.564, and 0.188) was evaluated by comparing the performance of configurations (1), (2), and (3), and is shown in Fig. 12.

Decreased jet thickness (t/h of 0.188) decreases the range potential to where the minimum range requirement could not be met. Both the expendable weight at zero range and the range peaked for base loadings at or below 20 lbs/ft^2, indicative of no further potential with increased base loading. (Increased base loading also results in an attendant increase in power requirements, propulsion system weight, structural weight, allowable fuel, payload, etc.) The decrease in expendable weight was naturally due to the poor hover efficiency of the small t/h ratio. Increasing the t/h to 0.564 increased the range potential with all engines operative, while range was essentially unchanged when half of the engines were shut down. The range requirement could be met, like configuration (1), with base loadings greater than 12.3 lbs/ft^2. At this base loading, the increased jet thickness configuration is capable of carrying 125 lbs of additional expendable weight. At 20-lbs/ft^2 base loading, the thicker jet configuration with all engines operative can carry 175 lbs of additional expendable weight (+4 percent), and its maximum range is increased 35 miles (+8 percent). This represents a 23-percent increase in payload at the short ranges. Range is increased a proportionally greater extent

than expendable weight due to a better match of power requirements between hover and cruise for the thicker jet system, resulting in decreased SFC's during cruise. With half of the engines shut down the maximum range of the basic jet thickness configuration is somewhat greater than the thick jet configuration, with 4-percent less expendable weight. This is due to the inability of the thicker jet system to operate with half of the engines inoperative over an appreciable range, due to the more even power match between hover and cruise [configuration (2) is more efficient during hover].

Jet Angle

The effect of leading and trailing edge jet angle (90, 120, and 60 degrees) was evaluated by comparing the performance of configurations (1), (4), and (5) respectively, and is shown in Fig. 13. The 60-degree jet deflection is clearly inferior to the other two jet angles, as would be expected. Four hundred mile range could be obtained at 16.5-lbs/ft^2 base loading, but clearly its potential (additional range, increased payload at range, etc.) when compared to the two other configurations is limited. For the same expendable weight as configuration (5), configuration (1) and (4) require base loadings of 13.6 and 13.2 lbs/ft^2 for ranges of 470 and 460 miles. At the same base loading of configuration (5) (10,810 lbs initial weight) the maximum ranges of (1) and (4) are 625 and 635 miles. An efficient hover configuration is critical in obtaining sufficient fuel for cruise, and this determines the potential of the vehicle. The effect of being able to shut down half of the engines at 20-lbs/ft^2 base loading in configurations (1) and (4) is to increase the range from 550 to 715 miles, and 680 to 740 miles, respectively.

Differential Jet Thickness

The effect of differential leading and trailing edge jet thicknesses is evaluated in Fig. 14. These tests were initially conducted to evaluate the effectiveness of

differential leading and trailing edge mass flows in locating the center of pressure ahead of the 50-percent ground effect base chord at hover. The effect on range and expendable weight can be seen by comparing the performance of configurations (1), (6), (7), (8), and (9). The base loading required for 400-mile range increased as much as 25 percent in the attempt to move the cp forward by increasing the thickness of the leading edge nozzle. At 20-lbs/ft^2 base loading, the expendable weight at zero range was decreased 6 percent and the range decreased 22 percent.

With respect to the angularly symmetrical jet configurations tested, configuration (4) (120-degree jet deflection at the leading and trailing edge) had the greatest range and expendable weight potential for any given initial gross weight. This was due primarily to its having the least required hover power installation. (A complete 120-degree deflection peripheral jet, including the tip jet, for the hover condition should further increase vehicle performance; however, this nozzle configuration could not be tested with the wind tunnel model utilized.) Expendable weight versus range for configuration (4) is shown in Fig. 15, shaft horsepower required versus velocity is shown in Fig. 16.

Fig. 15 shows that the 400-mile mission can be achieved with base loadings of 12.3 lbs/ft^2 or greater. By increasing the base loading to 20 lbs/ft^2, the additional payload at <u>400 miles range</u> is over 1700 lbs, or a 330-percent increase in payload. Maximum range with 750-lbs payload at 20 lbs/ft^2 is increased from 400 miles to 680 miles with all engines operating during cruise and to 740 miles with half the engines shut down. Fig. 16 indicates that the cruise power required for 12.3-lbs/ft^2 initial base loading at 100 miles per hour was critical for determining total power installation. The power required for cruise at 100 miles per hour, after fuel burn-off reduced the base loading to 9.6 lbs/ft^2, is very near the required power at hover and 12.3-lbs/ft^2 base loading. Only the high base loaded configurations cruising at their speed for minimum power can exploit multiple engine installations.

For comparative purposes, shaft horsepower versus velocity is given in Fig. 17 for configuration (4) if aerodynamic off-loading was entirely absent. The values shown were based upon the same efficiencies as in the off-loaded configuration and the equivalent shaft horsepower due to the dynamic head of inlet ingested air is also subtracted. With no aerodynamic off-loading the required shaft horsepower increases with speed from hover. Data presented in Ref. 12 were used to calculate the shaft horsepower of the 16-lbs/ ft^2 base loaded Saunders-Roe SR-N1 operating over water. This is also shown in Fig. 17. Comparing the data in Figs. 16 and 17 indicates that a 20-lbs/ ft^2 base loaded hovercraft type air cushion vehicle requires 3.65 times as much power at 100 miles per hour as an equivalent air cushion vehicle utilizing aerodynamic off-loading.

Since configuration (4) was the most efficient hover system, it was decided to use this as the basic hover configuration during the evaluation of variable leading and trailing edge nozzles for cruise. In addition, the resulting CRV's were assumed to cruise at 2.67 feet as well as 1.33 feet although <u>the installed power in both cases was that required to hover at 1.33 feet</u>. This was permitted due to the dissimilar power requirements when both the hover and cruise height are the same. In some cases the power to cruise at 2.67 feet was slightly greater than that required to hover at 1.33 feet. In these cases the expendable weight (zero range) was reduced to account for the increased powerplant weight. Since test data for configuration (4) were not obtained at a scaled cruise height of 2.67 feet, the configuration cruised at 2.67 feet are compared to configuration (1), for which test data were available and which approached configuration (4) in range and weight potential.

Differential Jet Thickness and Angle

The effect of differential jet thickness and jet angle for cruise at 1.33 feet is given in Fig. 18. Decreasing the thickness of the leading edge jet to a t/h of 0.188 and increasing the thickness of the trailing edge

jet to a t/h of 0.564 and deflecting it aft to the 60-degree position, configuration (12), resulted in approximately 10-percent increase in range for all base loadings with all engines operative (+25 percent for half engines operative) and at 400-mile range resulted in a 500-lbs reduction in gross weight (-7 percent). Closing down and fairing the leading edge nozzle and deflecting the basic thickness nozzle (t/h of 0.375) aft to the 60-degree position, configuration (13), increased the range another 10 percent and resulted in another 500-lbs reduction in gross weight for the 400-mile range. Increased range due to shutting down 50 percent of the engines increased with the increasingly more efficient cruise configurations.

The effect of differential jet thickness and jet angle for cruise at 2.67-feet height (power installed for 1.33 feet hover) is given in Fig. 19 and compared with configuration (1) operated in the same manner. Configurations (1), (12), and (13) are all capable of meeting the 400-mile requirement, although the basic hover configuration (1), could just make spe ified range.. The gross weights required by configurations (12) and (13) to meet the 400-mile range at 2.67-feet cruise are 11,920 lbs and 10,750 lbs, respectively, which compare with the gross weights of 7540 lbs and 7070 lbs, respectively, for cruise at 1.33 feet. Both configurations (12) and (13) required increased power to cruise at 2.67 feet over that to hover at 1.33 feet. The effect on expendable weight can be found in comparing Figs. 18 and 19.

Tip Jet Plus Jet Flap

The effect of closing down and fairing the leading edge jet and allowing the trailing edge jet nozzles to assume deflections of 30, 45, and 60 degrees, configurations (18), (19), and (20), for 1.33-feet cruise height is given in Fig. 20. Jet flaps greatly increase the range potential of these vehicles. The performance of the 30- and 60-degree jet flap configurations are equivalent and about 10 percent greater than the 45-degree system and about 50 percent greater than the basic hover configuration (4) (half engines operative during cruise). None of

these cruise configurations required increased power over that required for hover and therefore the expendable weight at zero range remains constant for all configurations.

These configurations are compared at 2.67-feet cruise height in Fig. 21. At this height the tip jet plus 60-degree jet flap exhibited maximum range potential. For the 400-mile range, an increase in base loading from 11 lbs/ft^2 to 13.5 lbs/ft^2 allowed the cruise height of the vehicle to be doubled. In addition, the expendable weight at zero range of the tip jet plus 60-degree jet flap configuration remained constant with respect to configuration (4) at 1.33 feet hover height due to excellent power matching between configuration (4) at 1.33-feet hover and configuration (20) at 2.67 feet cruise heights. The jet flap, utilized at cruise in conjunction with tip jets, forms in essence an end-plated ram wing which reduces the loss in cruise efficiency with height. At 1.33-feet height the 30- and 60-degree jet flaps offered the best range potential, while at 2.67-feet height the 60-degree jet flap appeared best. Variable configuration nozzles, at least at the leading and trailing edges, with the ability to close the leading edge nozzle, appear to be desirable in effecting efficient cruise.

Leading and Trailing Edge Jet Off

The cruise performance at 1.33 feet of the tip jet, configuration (21), is shown in Fig. 22. This configuration is an end-plated airfoil section flying at zero degree angle of attack, the "end-plates" being formed by the air jet issuing from the tips of the wings. This configuration has comparable range versus base loadings with respect to configuration (4) at this height. However, configuration (21) could not be operated at 2.67 feet, due to large decreases in cruise efficiency associated with the tip-jet-fed trapped vortex located between the base of the vehicle and the ground (Volume II). The addition of jet flaps (above) restrains the formation of these tip-jet-generated vortices. The decrease in cruise efficiency at this height resulted in such large installed power requirements that fuel was not permitted.

Shutting down the trailing edge jet flap and cruising on tip jets alone reduced the potential of these vehicles at 1.33-feet cruise height and did not permit them to cruise at 2.67 feet.

Number of Engines

Multiple engine installations, even for the integrated powerplant systems considered, also appear desirable in effecting efficient cruise. Due to the dissimilar power requirements between hover and aerodynamically off-loaded cruise at a given height, range at this height can be extended by shutting down a portion of the installed engines (turboprops or turboshafts) and operating the remainder at higher, but more economical, power settings. Thus, while the excess power available during cruise can result in higher cruise heights when higher heights are required, a multiple engine installation can afford large increases in range over that of a single engine installation, when only hover type cruise heights are required. The more efficient the cruise configuration, that is, the more effective the aerodynamic off-loading, the more advantageous a multiple engine installation is in achieving increased range. Although only a multiple-of-two engine installation with either all or one half the engines operating was investigated, it was evident during the course of the study that greater ranges could have been achieved in many instances with 3 out of 4, or 2 out of 3 engines operating.

Effect of Other Parameters

The effect of varying some of the assumed constants and restraints (page 8 and Appendix I) was investigated to judge their severity with respect to performance. The effect of varying drag, ducting efficiency, structural weight ratio, design altitude-temperature-conditions and design payload was investigated on configuration (4) for the CRV mission. These are shown in Figs. 23 through 27.

The effect of increasing drag 25, 50, and 75 percent is shown in Fig. 23. Between 12 and 16 lbs/ft^2 base loading, range was diminished 2.3 miles per percent drag increase. However, even with a 75 percent increase in drag, the 400 mile range can be met by increasing the base loading from 12.3 to 15.5 lbs/ft^2. Since the power at cruise was very close to that for hover at initial base loadings on configuration (4), increases in drag made the cruise conditions critical with respect to maximum installed shaft horsepower and therefore the 100 mile per hour speed requirement could only be met by decreasing the expendable weight (available fuel for example). This required expendable weight decrease was increasingly pronounced with decreasing base loading, very little effect being noticed at 20 lbs/ft^2, even with a 75 percent increase in drag.

The effect of decreasing duct efficiency is shown in Fig. 24. At high base loadings, reducing the ducting efficiency 14 percent, (from 0.7 to 0.6) had a larger effect on range than did a 75 percent increase in drag. This vastly greater effect on range with decreased ducting efficiency was due to the increased installed power required for hover. This is evident when comparing the expendable weight at zero range in Figs. 23 and 24. The decrease in expendable weight at high base loading was negligible for the increased drag case but extensive in the decreased ducting efficiency case. These large decreases in expendable weight together with the higher cruise shaft horsepowers required, coupled to decrease range precipitously. Thus, the 400-mile range that could be met with a vehicle of 12.3-lbs/ft^2 base loading and a ducting efficiency of 0.7, requires a base loading of 14 lbs/ft^2 for a ducting efficiency of 0.6, and cannot be met at all with a ducting efficiency of 0.5. Fig. 24 reveals that optimum base loadings (max range for given payload) increase with increased duct efficiencies.

The effect of varying the structural and equipment weight is shown in Fig. 25. The structural and equipment weight ratio was varied -10, +10, and +20 percent. Increasing the structural weight ratio has a large effect on range and expendable weight. Its effect is most pro-

nounced at the lighter base loadings since the structural and equipment weight ratio increases with decreasing base loading (Fig. 4). Fig. 25 indicates that increasing the structural and equipment weight ratio 20 percent reduces range 35 percent at 20-lbs/ft^2 base loading and 57 percent at 12-lbs/ft^2 base loading. For the 400-mile range, increasing the structural and equipment weight ratio 20 percent increased base loading from 12.3 to 16.9 lbs/ft^2, or 37.5 percent.

The effect of design temperature-altitude-condition is given in Fig. 26. The design temperature-altitude-condition was first relaxed from 90 degrees F. at sea level to standard condition at sea level and then increased in severity to 90 degrees F. at 6000 feet. The effect on range and expendable weight is seen to be small with respect to the mean condition chosen.

The effect of increasing the fixed design payload on the CRV, (say, additional crew, mine detection system, night time infrared viewing equipment, armor plate, shovels, mechanical saws, etc.) is given in Fig. 27. Doubling the payload of the CRV vehicle increases the base loading of the vehicle from 12.3 to 15.3 lbs/ft^2, or roughly 24 percent, for 400-mile range. This smaller ratio of gross weight to payload increase is due to the small percentage of design payload originally stipulated. The addition of an additional crewman, his personal equipment, and the necessary installed weight to accomodate him, say 250 lbs, at the design stage, only causes nominal increases in base loading.

PERFORMANCE OF THE LOGISTICS VEHICLE

The LV was analyzed using the first 9 jet configurations operating at the stipulated height of 2.0 feet and cruise speed of 60 miles per hour. In addition, the best jet configuration of the above 9 was then analyzed at a cruise speed of 100 miles per hour and further analyzed with the addition of jet flap trailing edges at 100 miles per hour cruise speed. Lastly, the jet flapped configuration was analyzed at a cruise speed of 100 miles per hour and cruise height of 4.0 feet. The data are presented as expendable weight versus range, to allow eval-

uation of the effect of increased payload on range, and as range versus initial base loading for the 5000-lbs (specified) and 2000-lbs. payload. The data for the first 9 configurations are presented in Figs. 28 through 36.

With 5000-lbs payload, none of the first 9 jet configurations, operating at a cruise speed of 60 miles per hour, can meet the "required" 480-mile range; nor can this range be met with 2000 lbs of payload. The best configuration is configuration (4) (as it was in the 100-mile per hour CRV mission) which will allow 1300 lbs of payload to be carried 480 miles or will carry 5000 lbs of payload 260 miles. The reduction of installed powerplant weight afforded by (4) was the determining factor.

Configurations (1) and (2) compare with configuration (4) as follows:

Config.	RANGE		PAYLOAD	
	5000 lbs. payload	2000 lbs. payload	480 miles range	240 miles range
4	260 miles	430 miles	1300 lbs.	5400 lbs.
1	170	302	-	3300
2	196	343	-	4000

Reducing the range to one half of that "required" (that is, 240 miles) results in usable vehicles with jet configurations (1), (2), and (4). The other 6 configurations did not show any weight carrying capabilities beyond 2000 lbs, even at the 240-mile range.

Although the maximum load carrying capability was exhibited at the heaviest base loading investigated, maximum range at the reduced payload of 2000 lbs occurred at initial base loadings less than 20 lbs/ft^2,(19 lbs/ft^2 for configurations listed above). These maximum ranges at reduced payloads were obtained by shutting down one half of the installed engines when the reduced weight of the vehicle (due to fuel burn-off) would permit allowable

power settings of the remaining engines. For configuration (4), maximum range for 2000-lbs payload was increased from 385 to 430 miles by this process.

Since minimum power with velocity was not exhibited at 60 miles per hour (Fig. 16 but with the required shaft horsepower multiplied by 2.25 to make it applicable to the LV) it was decided to evaluate configuration (4) at 100-miles per hour cruise speed. Fig. 37 illustrates the results of this investigation for 5000-lbs payload. The "required" 480-mile range can almost be met, short by 40 miles. A vehicle with a base loading of approximately 21.6 lbs/ft^2 (31,850-lbs gross weight) would satisfy this range "requirement," although endurance would only be 4.8 hours, instead of the stipulated 8 hours. At 240 miles, 7700 lbs of payload can be carried with an initial base loading of 20 lbs/ft^2.

It was also decided to evaluate the LV at 100-miles per hour cruise with the best cruise-jet flap configuration indicated by the CRV analysis for this height-size ratio. Fig. 38 illustrates the results of the 5000-lbs payload LV using configuration (4) for hover and operating during cruise with the front jet closed and faired and a 30-degree jet flap, configuration (18), at the trailing edge. The 480-mile range requirement can be met with 5650-lbs payload, or the 5000-lbs payload can be carried 540 miles with 20-lbs/ft^2 initial base loading or 480 miles at 18-lbs/ft^2 initial base loading.

With the payload-range requirement exceeded, it was decided to evaluate configuration (4) at 4.00-feet cruise height and add the best cruise - jet flap configuration indicated for this height-size ratio in the CRV mission analysis. The total installed power is still that required to hover at 2.00 feet with configuration (4) but now cruise is at 4.00 feet with configuration (20). The results are presented in Fig. 39. Although the initial expendable weight remains the same, due to the good power matching between high cruise - low hover height, fuel is very rapidly diminished due to the high cruise power required. Still, 5000 lbs of payload can be carried 367 miles, which is more than 100 miles greater than the fixed

jet system operating at 60 miles per hour and 2.0-feet cruise height.

The four configurations evaluated above are compared directly in Fig. 40 for the 5000-lbs payload case. Some pertinent results are tabulated below. Gross weights for these vehicles are included for each result.

Conf.	MPH	Cruise Height	Range 5000 lbs Payload	Payload 480 Miles Range	Payload 240 Miles Range
4	60	2.0'	260 miles 29500 lbs	1300 lbs 29500 lbs.	5400 lbs 29500 lbs
4	100	2.0'	440 miles 29500 lbs 480 miles 31850 lbs	4500 lbs 29500 lbs 5000 lbs 31850 lbs	7700 lbs 29500 lbs 5000 lbs 22100 lbs
4-18	100	2.0'	542 miles 29500 lbs 480 miles 26550 lbs	5650 lbs 29500 lbs 5000 lbs 26500 lbs	8350 lbs 29500 lbs 6300 lbs 20000 lbs
4-20	100	4.0'	367 miles 29500 lbs 390 miles 34700 lbs	- -	7000 lbs 29500 lbs 5000 lbs 23300 lbs

The range of the last three vehicles, as well as their additional payload carrying capability, can be increased by increasing the initial base loadings (gross weight) whereas maximum range had peaked for the first vehicle, configuration (4) at 60 miles per hour, at an initial base loading of 19 lbs/ ft^2.

Maximum cruise efficiency for the LV is thus achieved by designing the vehicle so as to be able to obtain aerodynamic lift, and then by operating it at speeds that will allow the aerodynamic lift to be realized. The total power required at speed is considerably less for the aerodynamically off-loaded vehicle than for the non-aerodynamically off-loaded (SR-N1 type) vehicle.

CONCLUSIONS

Selected vehicles for the command reconnaissance and logistics missions outlined in Ref. 1 were analyzed with the data obtained in this wind tunnel investigation. Relaxation of one of the four mission requirements allowed the other three to be met or approached. This was especially true with respect to the maximum hover capability of the CRV and the mission duration of the LV.

Reducing the hover height capability of the CRV from 4.00 feet to 1.33 feet allowed the CRV mission to be achieved at 1.33-feet cruise height and in some cases 2.67-feet cruise height.

Reducing the mission duration of the LV from 8 hours to 4 hours allowed the remainder of the mission requirements to be achieved. Reducing the payload from 5000 lbs to 2000 lbs almost provided specified duration. Alternatively, increasing the cruise speed allowed the specified range with 5000-lbs payload (although not the endurance) to be met.

Cruise performance of these vehicles demanded efficient hover configurations so that sufficient fuel could be carried. The best hover configuration tested was the 120-degree jet deflection nozzles at the leading and trailing edges (the tip jets were fixed at 90 degrees in this investigation). However, cruise range could be increased 50 percent or more by providing jet flap trailing edge nozzles and closing or fairing the leading edge nozzles. Variable configuration nozzles, at least at the leading and trailing edges, appear to be highly desirable in effecting aerodynamic off-loading and efficient cruise.

Multiple engine installations with turboprop engines also appear highly desirable in effecting efficient cruise. The dissimilar power requirements between hover and cruise in high base loaded vehicles can be exploited in increased range by shutting down some portion of the installed engines and operating the remainder at higher but more efficient cruise power settings.

Speed for minimum power requirements is a function of base loading (and parasite drag). For the configurations in these tests, 100 miles per hour offered the lowest required power for 20 lbs/ft^2 base loading.

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APPENDIX I

PERFORMANCE CALCULATION METHOD

The expendable weight/range curves were calculated using a variation of the growth factor equation

$$W_G = \frac{W_{P/L}}{1 - K_{S+E} - K_{F+FS} - K_{P_i}}$$

where

W_G = Initial gross weight, a function of base loading and hover height.

$W_{P/L}$ = Payload weight, 750 lbs. for the CRV and 5000 (or 2000) lbs. for the LV.

K_{S+E} = Structure and equipment weight to gross weight ratio.

K_{F+FS} = Fuel and fuel system weight to gross weight ratio.

K_{P_i} = Installed powerplant to gross weight ratio.

The three ratios are derived below.

The structure and equipment weight to gross weight ratio is equal to

$$K_{S+E} = \frac{W_{structure} + W_{equipment}}{W_G}$$

This ratio, a function of planform loading (Fig. 4), was obtained from Ref. 5, and represents the bottom of the envelope of structural weight ratios for light to medium impact load conditions. The planform to base loading

ratio is 0.833 for the structural overlap of the basic configuration. At each base loading this ratio was considered invariant with respect to the addition of variable leading and trailing edge nozzles. (If desired, a penalty can be added for these features by claiming this weight, if estimatable, as "additional" payload.)

The fuel and fuel system weight to gross weight ratio is equal to

$$K_{F+FS} = \frac{W_{fuel} + W_{fuel\ system}}{W_G} = \frac{K_{i_f}\,(W_{fuel})}{W_G}$$

$$= \frac{K_{i_f}\left[SHP_{inst} \times P/S \times SFC_{MRP} \times F_{P/S} \times \text{hours}\right]}{W_G}$$

where

K_{i_f} = Total fuel plus fuel system weight to fuel weight ratio. This was taken as 1.1 (Ref. 5).

SHP_{inst} = installed shaft horsepower. This is equal to military rated power of the engines times the number of engines operating at cruise condition.

P/S = power setting of the engines operating at cruise condition expressed as percent of military rated power.

SFC_{MRP} = specific fuel consumption at military rated power, lbs of fuel per shaft horsepower-hour. The value 0.67 was considered typical of light to medium turboprops at sea level, low speed conditions (Refs. 6 and 7).

$F_{P/S}$ = ratio of SFC at a particular P/S to the SFC at MRP. This ratio was obtained from Ref. 6 and is shown in Fig. 5.

The ratio K_{F+FS} can therefore be expressed as

$$K_{F+FS} = .737(SHP_{cruise} \times F_{P/S\ \text{eng. oper.}} \times \frac{\text{range}}{V}) \frac{1}{W_G}$$

The final ratio, the <u>installed powerplant to gross weight ratio</u>, is equal to

$$K_{P_i} = K_i \left(\frac{W_{P_o}}{SHP_o} + \frac{W_{fan} + W_{prop}}{SHP_o} + \frac{W_{trans}}{SHP_o}\right) \frac{SHP_o}{W_G}$$

where

K_i = <u>propulsion system installation factor</u>. This factor was taken as 1.3 (Ref. 5).

$\frac{W_{P_o}}{SHP_o}$ = <u>engine specific weight based on MRP</u>. This was taken as 0.4 lbs/SHP for turboprop engines (Refs. 5 and 7).

$\frac{W_{fan} + W_{prop}}{SHP_o}$ = <u>fan plus propeller specific weight</u>. This was taken as 0.3 lbs/SHP for integrated powerplant systems where the maximum horsepower can be delivered, alternately, to the fan or the propeller (Ref. 5).

$\frac{W_{trans}}{SHP_o}$ = <u>transmission specific weight</u>. This was taken as 0.2 lbs/SHP for integrated powerplant systems (Ref. 5).

SHP_o = <u>total installed shaft horsepower</u>.

The total installed horsepower was calculated using the maximum horsepower required between hover and cruise speed (100 mph for the CRV and 60 mph for the LV) for standard day at sea level conditions, and factored for both a temperature-altitude-condition and an excess power margin

for control. This can be expressed as

$$SHP_o = SHP_{(h \text{ to } c)max} \times \text{temp-alt-factor} \times \text{thrust margin}$$

The temperature-altitude-condition considered critical was 90°F. at sea level, and the excess power margin for control at this critical condition was 5 percent.

This critical temperature-altitude-condition is essentially in agreement with the VTOL requirement stipulated in Ref. 8. Since lift/air horsepower is independent of altitude (Ref. 9) the temperature-altitude factor was considered to be a function of engine type only. The effect of critical temperature-altitude on shaft horsepower for turboprop engines was obtained from Ref. 10. The effect was to increase the installed shaft horsepower above that deemed necessary for sea level hover (or maintain height at speed) operation by 18.5 percent. Although the excess power margin for control was but 5 percent, the excess thrust margin is approximately 15 to 20 percent of gross weight, due to the thrust/power ratio of the propellers. Thus a 5-percent power margin is considered adequate for control of air cushioned vehicles at low speeds.

Returning now to the ratio K_{P_i}, we can express it as

$$K_{P_i} = 1.3(0.4 + 0.3 + 0.2) \frac{SHP_o}{W_G}$$

$$K_{P_i} = 1.17\left(\frac{SHP_o}{W_G}\right)$$

The power required for sea level operation was evaluated using the data in Volume II with efficiencies believed realistic for these vehicles and biased for the temperature-altitude condition. It was shown in Volume II that the shaft horsepower required for cruise (or at any speed) can be obtained from the equation,

$$SHP_{REQ'D} = \frac{qSV}{550}\left\{\frac{C_D}{\eta_P} + \frac{C_\mu}{\eta_P}\left(\frac{V}{V_{j_o}}\right) + \frac{C_\mu}{2}\left[\frac{1}{(V/V_{j_o})}\frac{1}{\eta_D}\frac{1}{\eta_F} - \left(\frac{V}{V_{j_o}}\right)\frac{\eta_I}{\eta_F}\right]\right\}$$

The shaft horsepower required at speed is a function of the parameters C_D, C_μ, and (V/V_{j_o}). For a design C_L (a function of base loading and velocity), C_μ and (V/V_{j_o}) were obtained from Figs. 10-61 of Volume II. C_D as a function of C_μ is presented in Figs. 6 and 7. The data in Fig. 6 are a compilation of the drag data for the symmetrical jet configurations while the drag data for the unsymmetrical configurations are presented in Fig. 7 (see Volume I). This data, along with the pertinent efficiencies assumed for fan, ducting, propulsive system, and inlet recovery, provided the necessary inputs for the calculation of the required shaft horsepower from 40 mph to cruise speeds.

The shaft horsepower required for hover was calculated by using the data presented in Figures 62-68 of Volume II. These figures allowed direct calculation of lift/shaft horsepower from experimentally obtained values of lift/air horsepower and base loadings, when fan and ducting efficiencies were added. Typical ranges of shaft horsepower required from hover to cruise speed for base loadings between 9 and 20 lbs/ft^2 are shown in Figs. 9 and 10 for the CRV and LV respectively. It will be immediately noted that the cruise speed stipulated for the LV was much too low with respect to speed for minimum power, especially at the more practical base loadings of 16 and 20 lbs/ft^2. The dip in the shaft horsepower required between 0 and 60 mph was typical for the high base loadings and was due to the thrust (negative drag) of the configuration in this range (Figs. 6 and 7).

The nominal efficiencies used in the above evaluation were

$$\eta_D = .70$$

$$\eta_F = .80$$

$\eta_I = .95$

η_P = a function of velocity and presented in Fig. 8.

Although air cushion vehicles will probably utilize shrouded propellers for propulsion (for both increased low speed efficiency and crew protection) propeller efficiencies of Ref. 11 (presented in Fig. 8) were used since available experimental data on shrouded propellers indicated lower efficiencies in the high end of the speed range. It is thought that eventual full scale shrouded propeller development would result in efficiencies equal or greater than those used.

When all of these developments are taken into account, the growth factor equation presented on page 28 can be expressed as

$$W_G = \frac{W_{P/L}}{1 - \left[1.17 \frac{SHP_o}{W_G} + .737 (SHP_c \times F_{P/S} \times \frac{\text{range}}{\text{Vel.}}) \frac{1}{W_G} + \frac{W_{S+E}}{W_G} \right]}$$

Rewriting the above to express range as the dependent variable

$$\text{Range} = \frac{(W_G - 1.17 SHP_o - W_{S+E} - W_{P/L})\ V}{.737\ SHP_c \times F_{P/S}}$$

$$= \frac{W_{F+FS}\ V}{.737\ SHP_c \times F_{P/S}}$$

In differential form,

$$dR = \frac{V \quad dW}{.737\ SHP_c \times F_{P/S}}$$

Integrating,

$$\text{Range} \cong \frac{V}{..737} \int_{0}^{W_{F+FS}} \frac{dW}{SHP_c \times F_{P/S}}$$

The range for each configuration was evaluated by step integration, using appropriate average values of SHP_c and $F_{P/S}$ at each interval. The results were then plotted as range versus expendable weight over a range of initial base loadings from 9 to 20 lbs/ft^2 (initial gross weights 5895 to 13,100 lbs.) for each configuration, and then cross plotted as range versus base loading (see page 7). In addition, the expendable weight at zero range was plotted versus base loading to facilitate comparisons between installed engine weight, which was a function of hover efficiency or in some cases, decreased cruise efficiency. For short range operation the expendable weight at zero range can indicate the increase in payload that could be carried by these vehicles. Base loading was used as the basic parameter instead of gross weight to facilitate scaling these data to larger vehicles at the same height-size ratio.

APPENDIX II

SUMMARY OF NOZZLE CONFIGURATIONS

Config. No.	$\theta_{j_{FWD}}$ (deg)	$\theta_{j_{AFT}}$ (deg)	Command Reconnaissance Veh. t_{FWD} (inches)	Command Reconnaissance Veh. t_{AFT} (inches)	Logistics Vehicle t_{FWD} (inches)	Logistics Vehicle t_{AFT} (inches)	Notes
1	90	90	6.0	6.0	9.0	9.0	AR = .833 Wing
2	90	90	9.0	9.0	13.5	13.5	
3	90	90	3.0	3.0	4.5	4.5	
4	120	120	6.0	6.0	9.0	9.0	
5	60	60	6.0	6.0	9.0	9.0	
6	90	90	7.54	4.53	11.3	6.8	
7	90	90	9.0	3.0	13.5	4.5	
8	90	90	4.53	7.54	6.8	11.3	
9	90	90	3.0	9.0	4.5	13.5	
10	120	60	9.0	3.0	13.5	4.5	
11	120	60	6.0	6.0	9.0	9.0	
12	120	60	3.0	9.0	4.5	13.5	
13	---	60	---	6.0	---	9.0	
14	60	120	9.0	3.0	13.5	4.5	
15	60	120	6.0	6.0	9.0	9.0	

APPENDIX II

SUMMARY OF NOZZLE CONFIGURATIONS (Cont.)

Config. No.	$\theta_{j_{FWD}}$ (deg)	$\theta_{j_{AFT}}$ (deg)	Command Reconnaissance Veh. t_{FWD} (inches)	Command Reconnaissance Veh. t_{AFT} (inches)	Logistics Vehicle t_{FWD} (inches)	Logistics Vehicle t_{AFT} (inches)	Notes
16	60	120	3.0	9.0	4.5	13.5	AR = .833 Wing.
17	---	120	---	6.0	---	9.0	
18	---	30JF	---	6.0	---	9.0	Jet Flap T.E.
19	---	45JF	---	6.0	---	9.0	Jet Flap T.E.
20	---	60JF	---	6.0	---	9.0	Jet Flap T.E.
21	---	---	---	---	---	---	Tip Jets Only

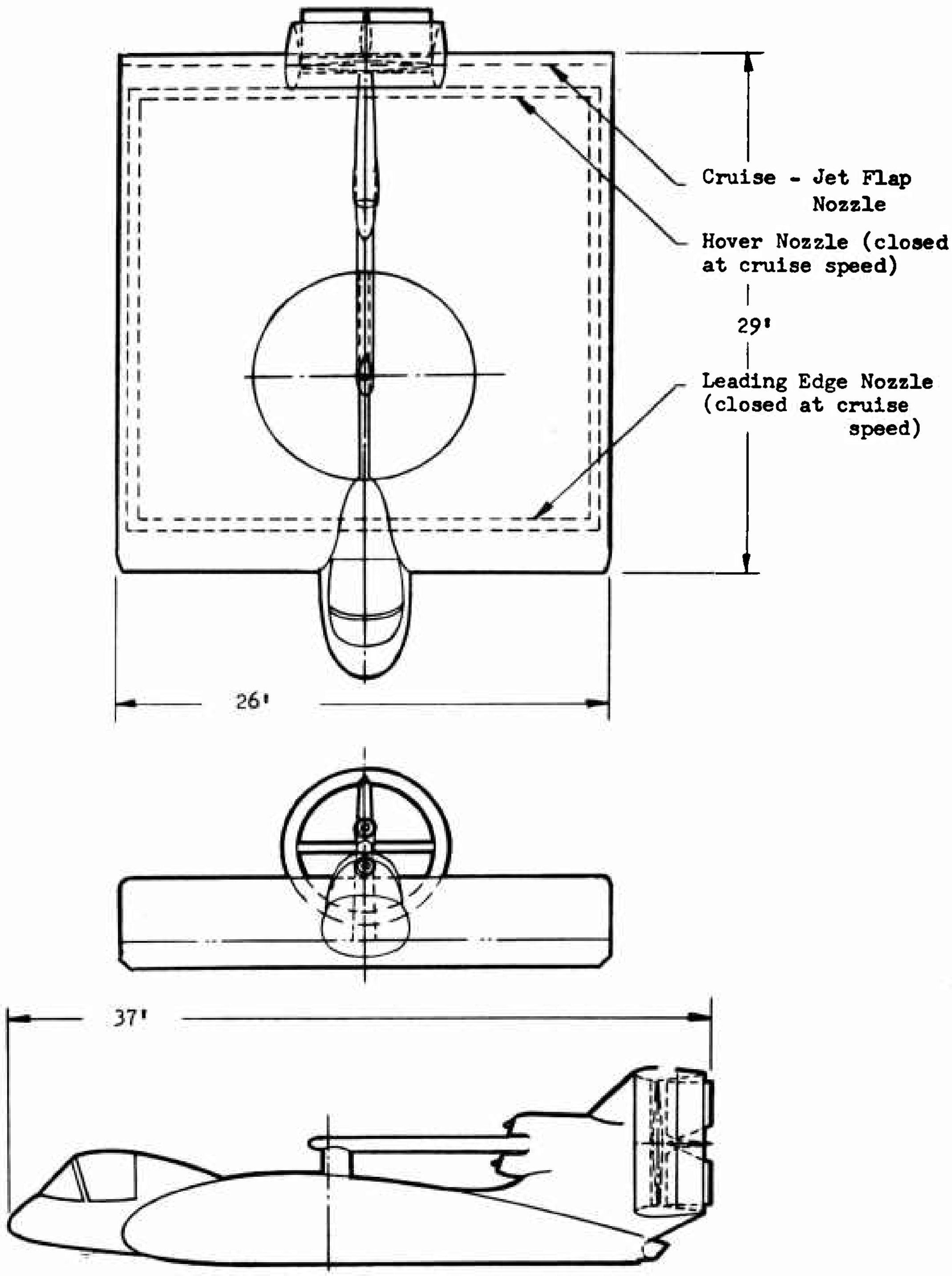


Fig. 1 Command Reconnaissance Vehicle

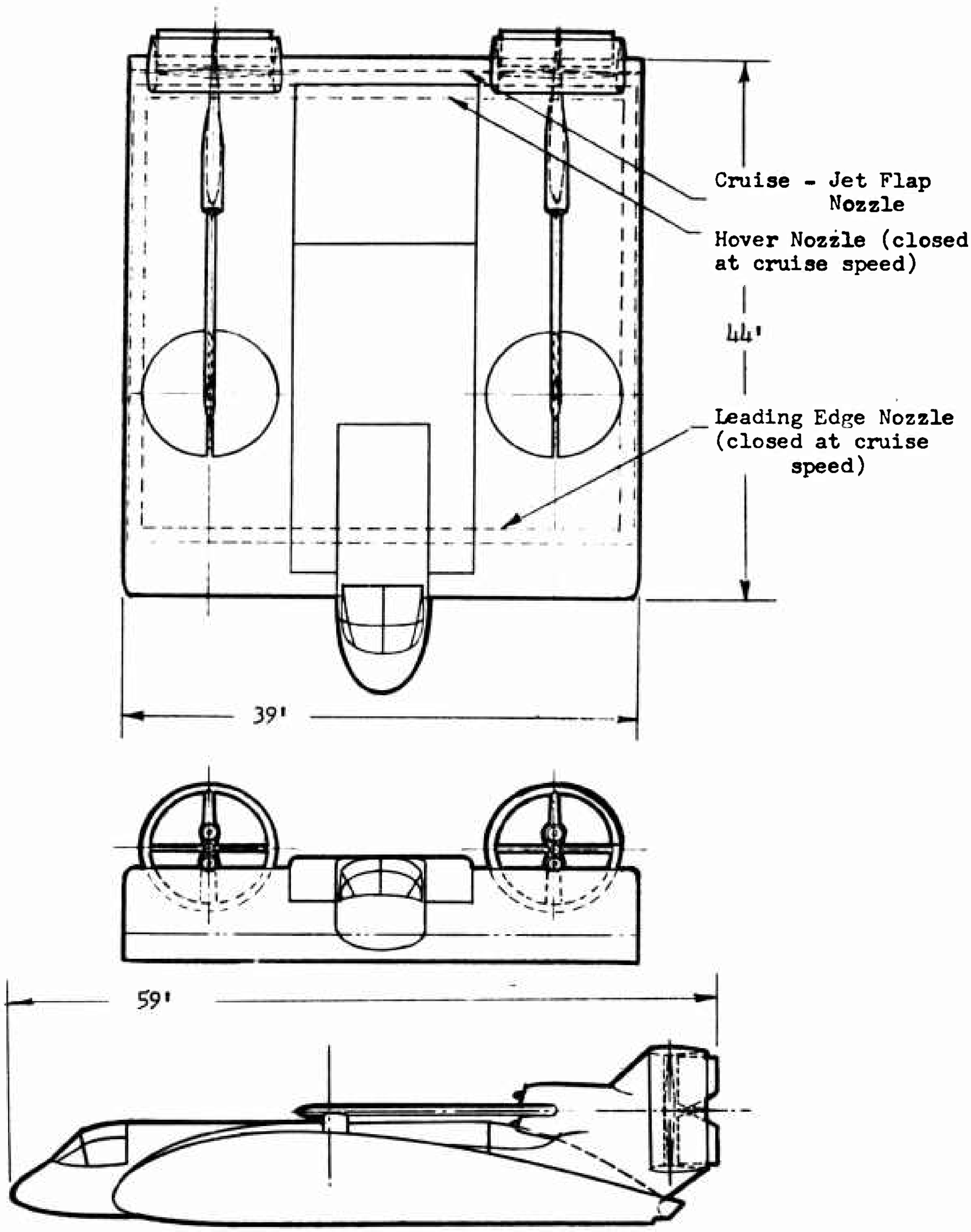


Fig. 2 Logistics Vehicle

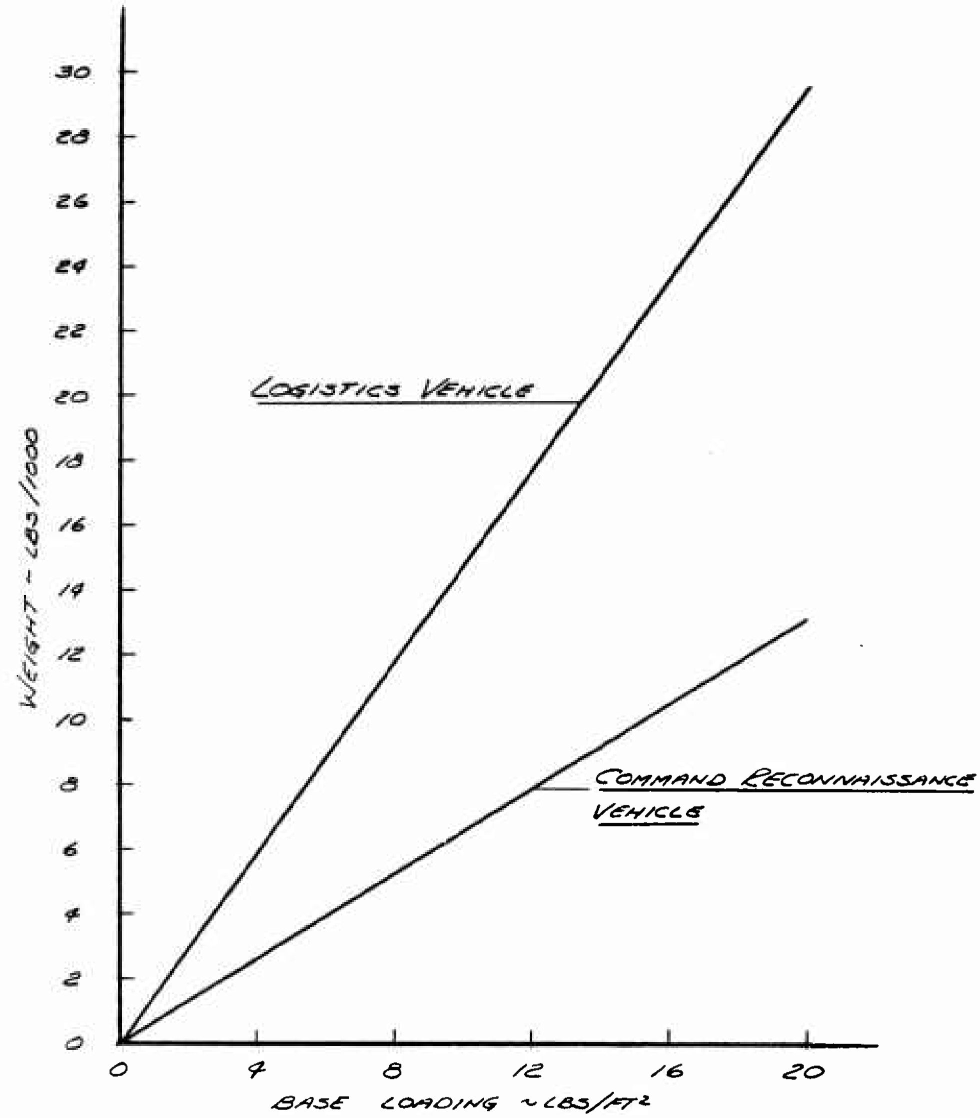


Fig. 3 Weight vs. Base Loading

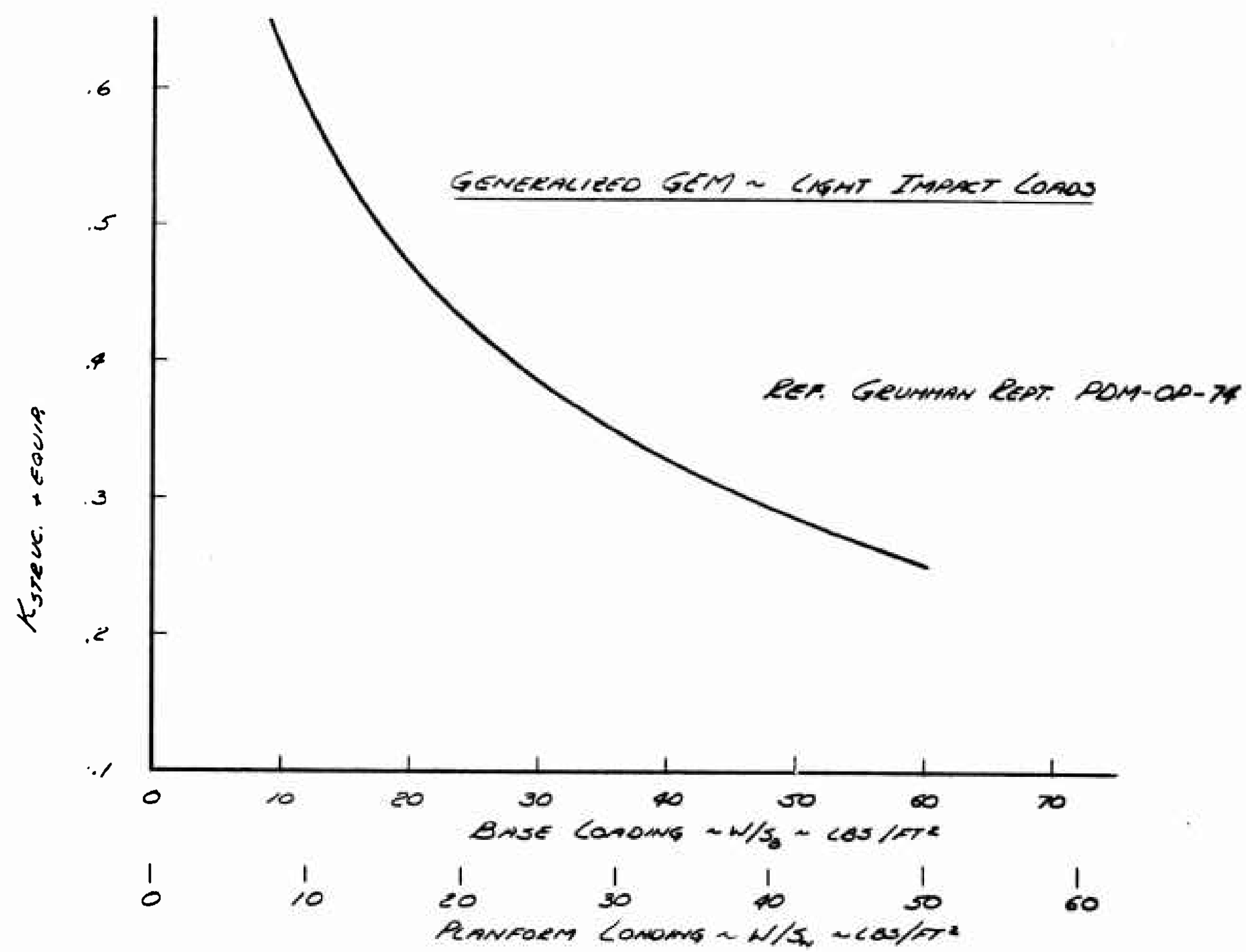


Fig. 4 Structural and Equipment Weight Factor

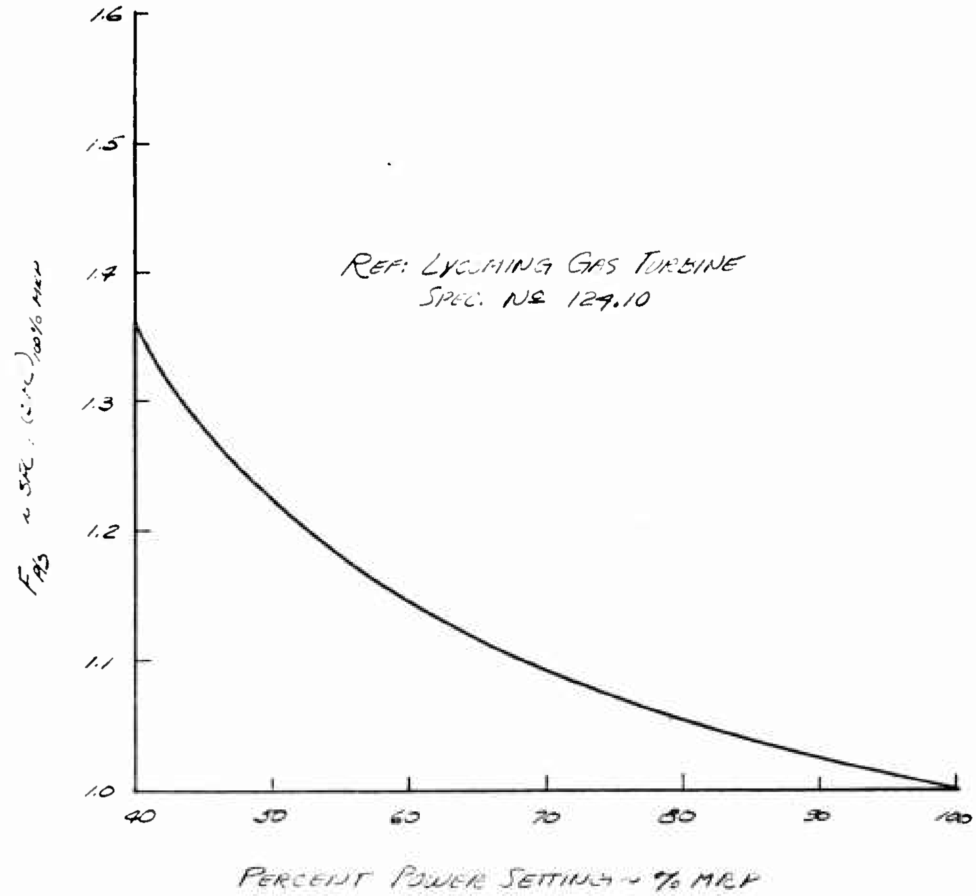


Fig. 5 Variation of Specific Fuel Consumption with Power Setting

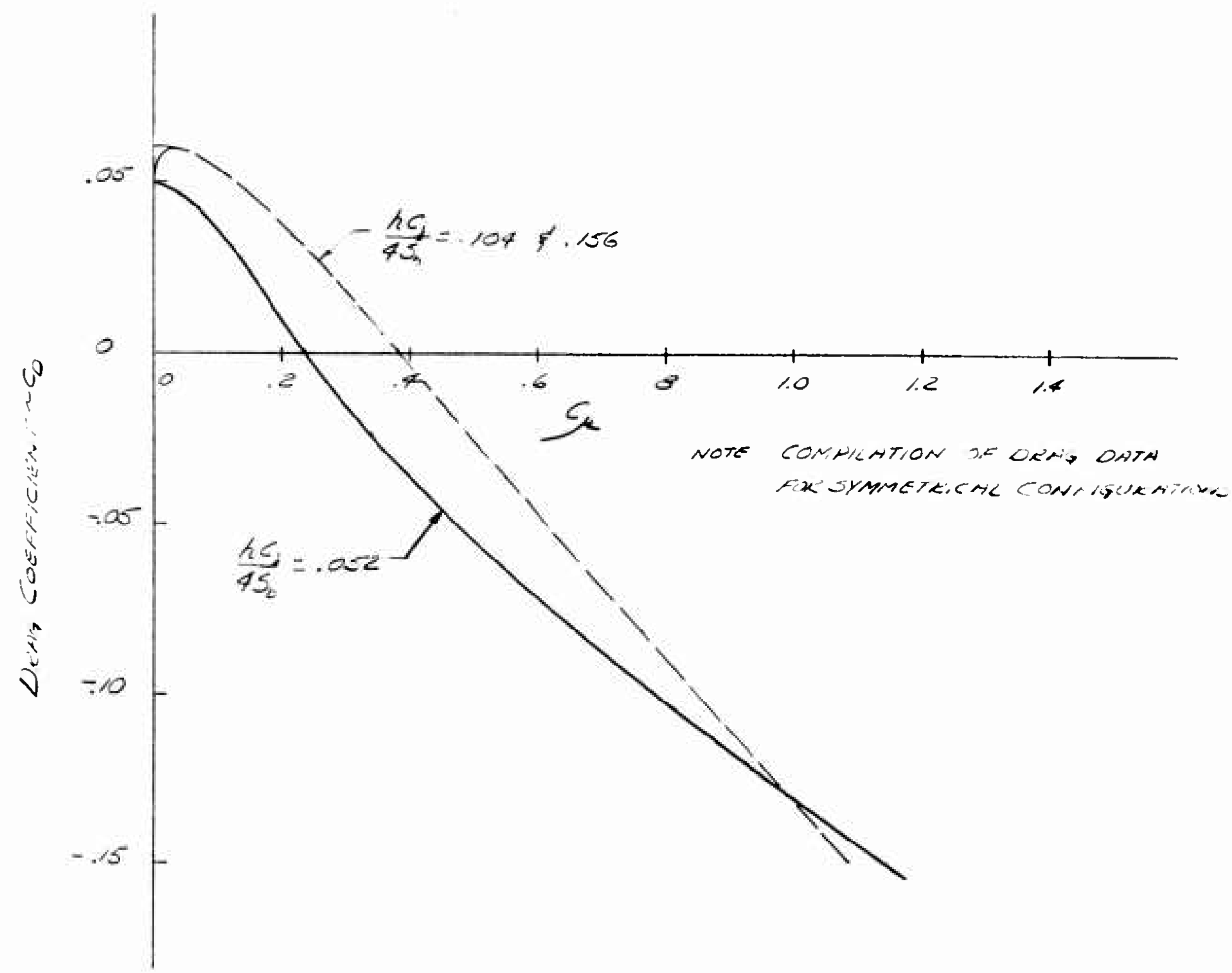


Fig. 6 C_D vs. C_μ - Symmetrical Configurations

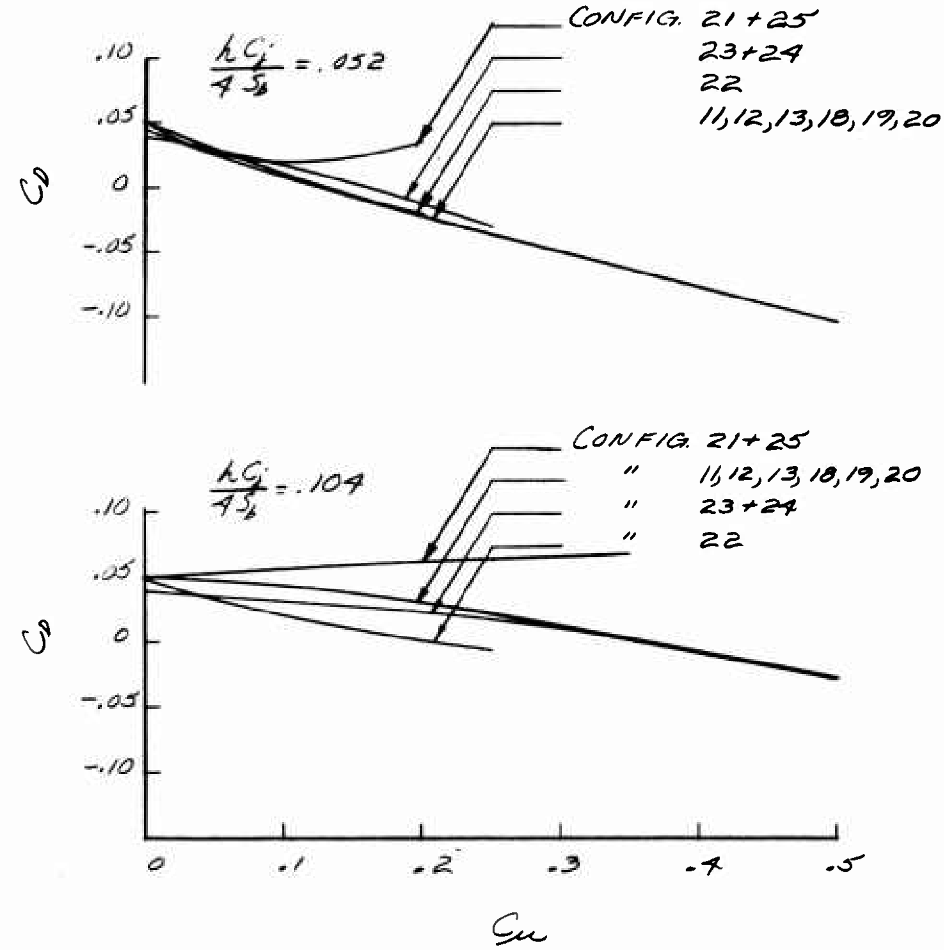


Fig. 7 C_D vs. C_μ - Unsymmetrical Configurations

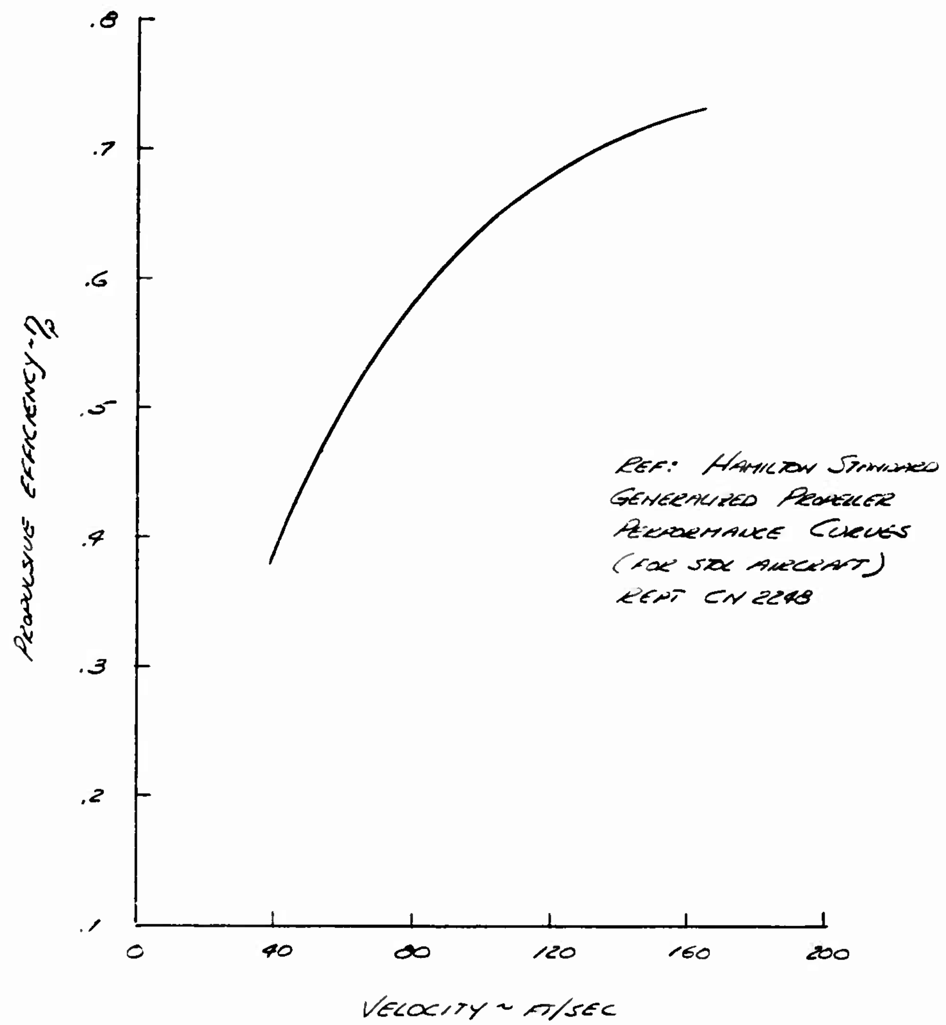


Fig. 8 Propulsive Efficiency vs. Forward Velocity

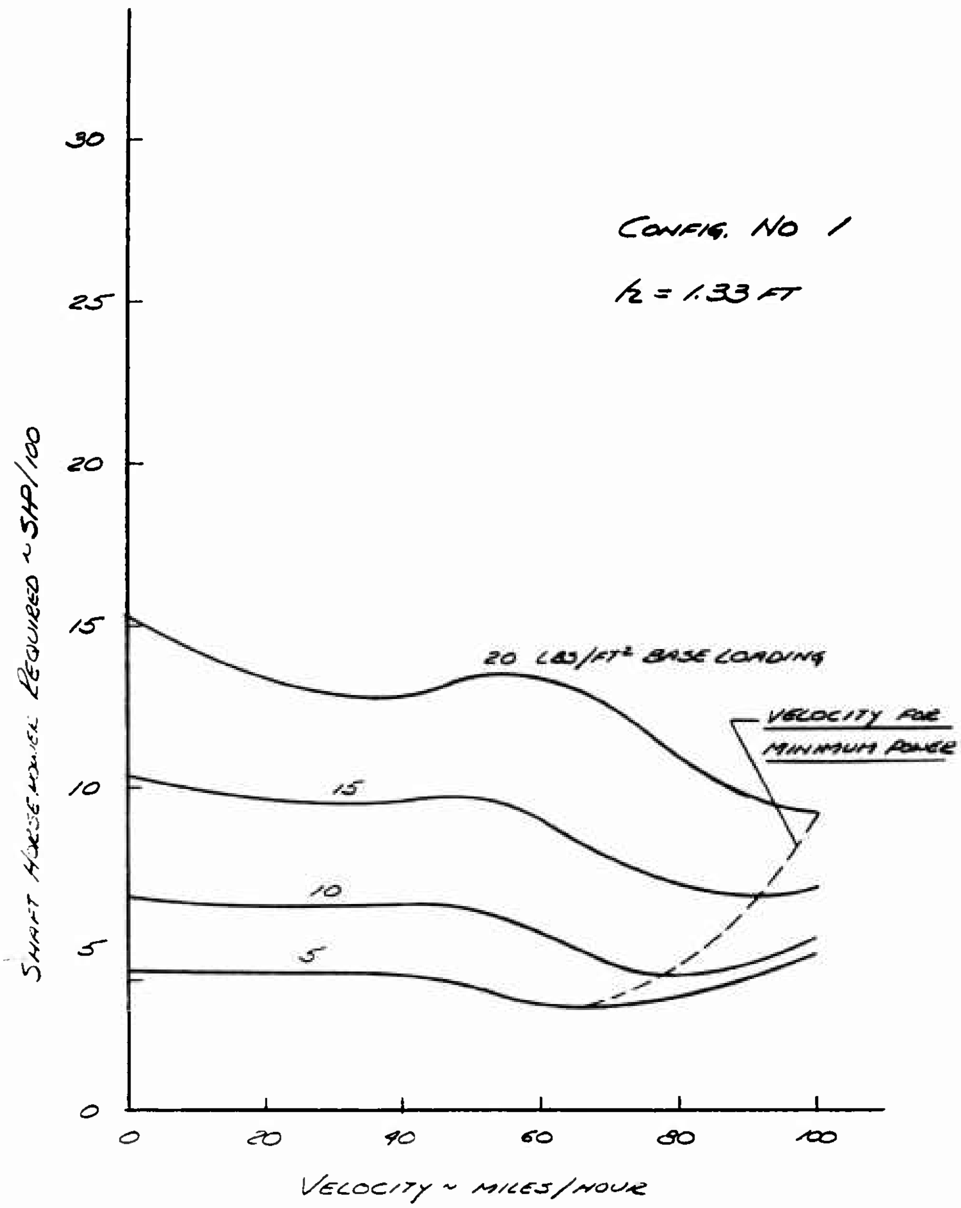


Fig. 9 Typical Range - Shaft Horsepower Required vs. Velocity - Command Reconnaissance Vehicle

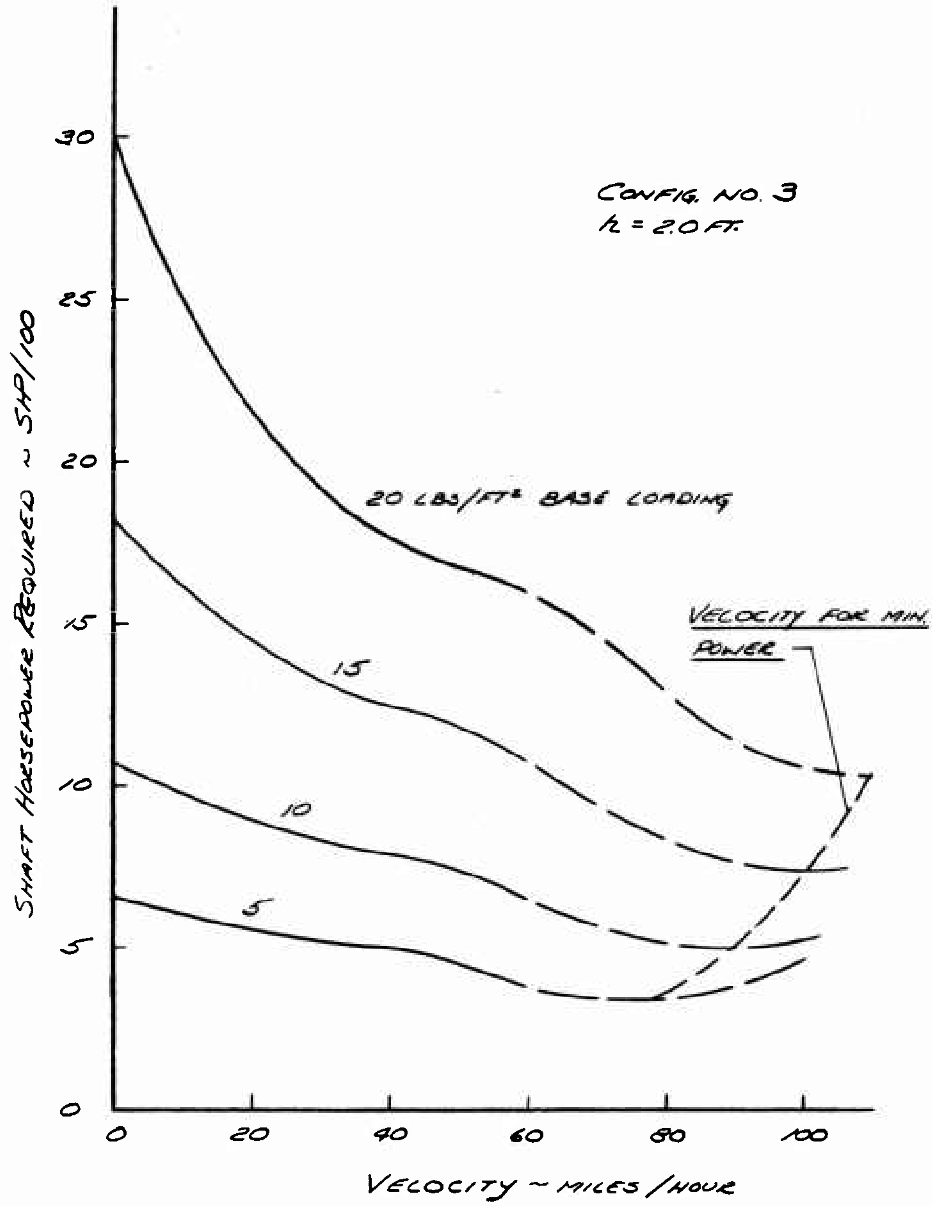


Fig. 10 Typical Range - Shaft Horsepower Required vs. Velocity - Logistics Vehicle

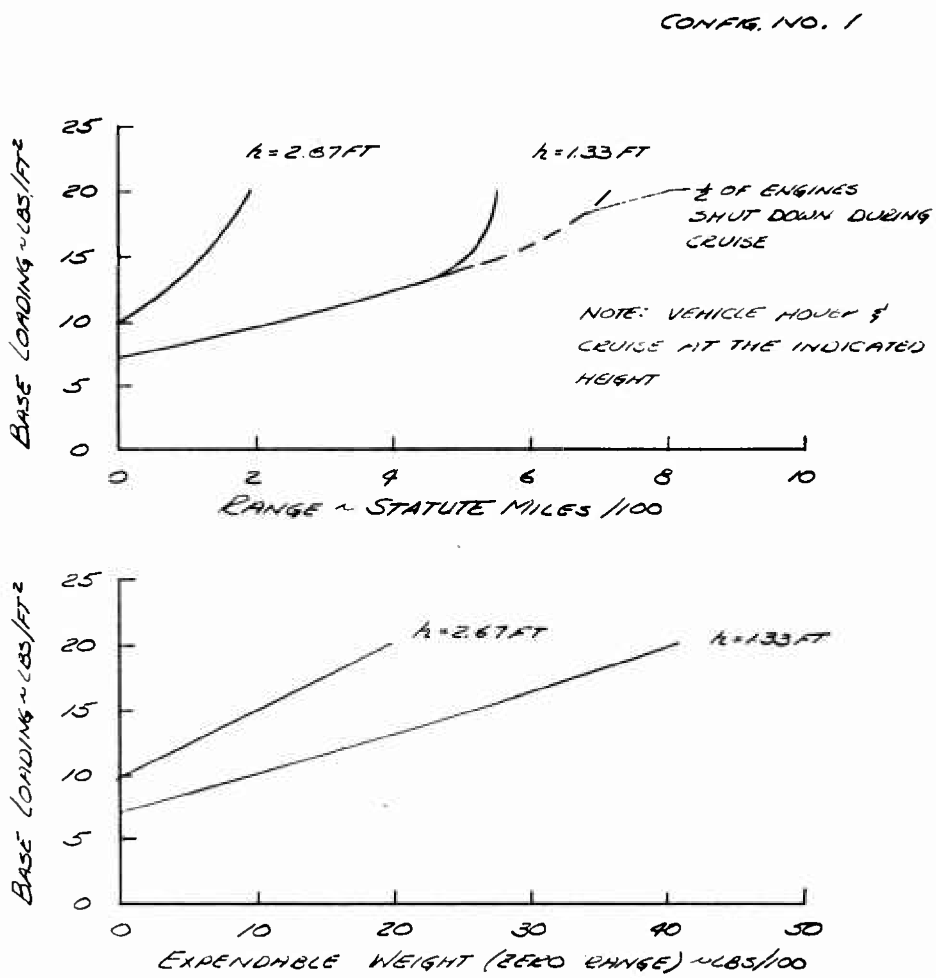
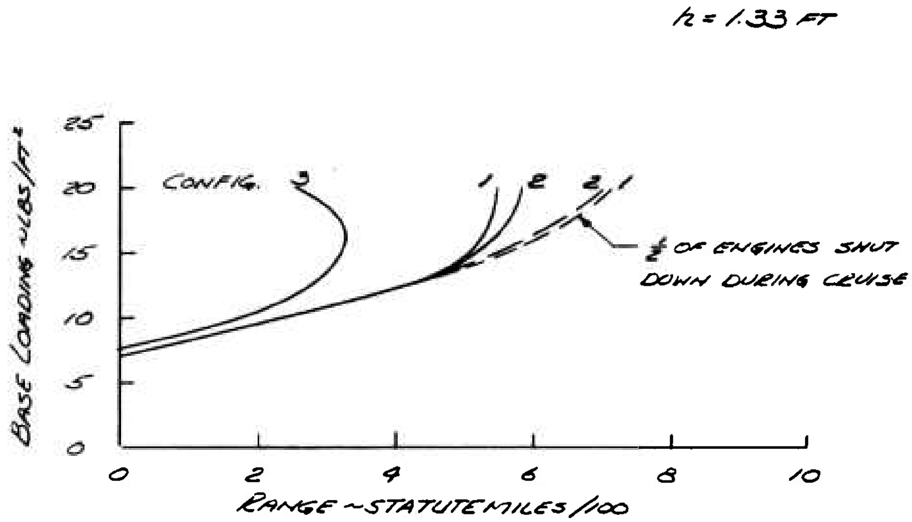


Fig. 11 Effect of Height - CRV



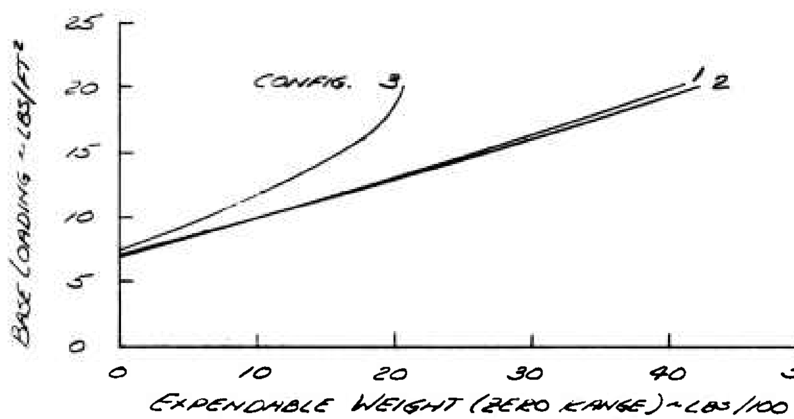


Fig. 12 Effect of Jet Thickness - CRV

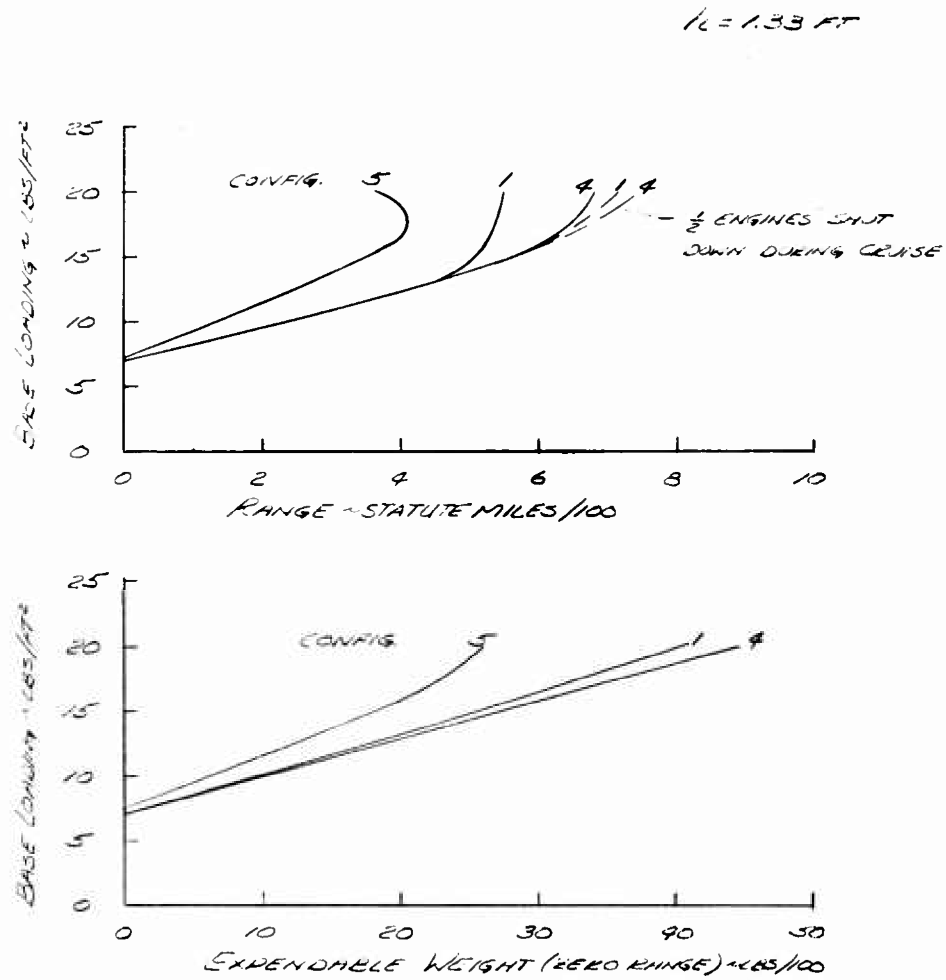
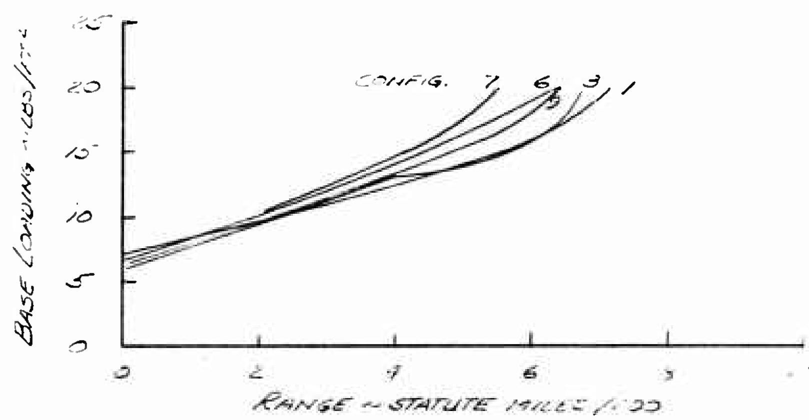


Fig. 13 Effect of Jet Angle - CRV

h = 1.33 FT



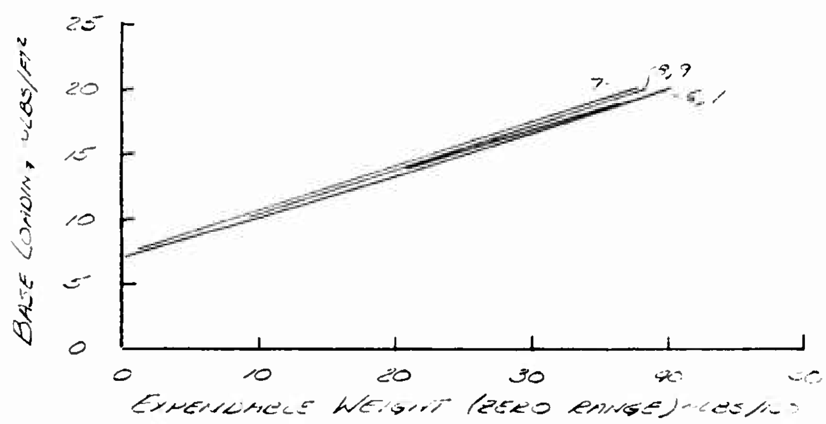


Fig. 14 Effect of Differential Mass Flows - CRV

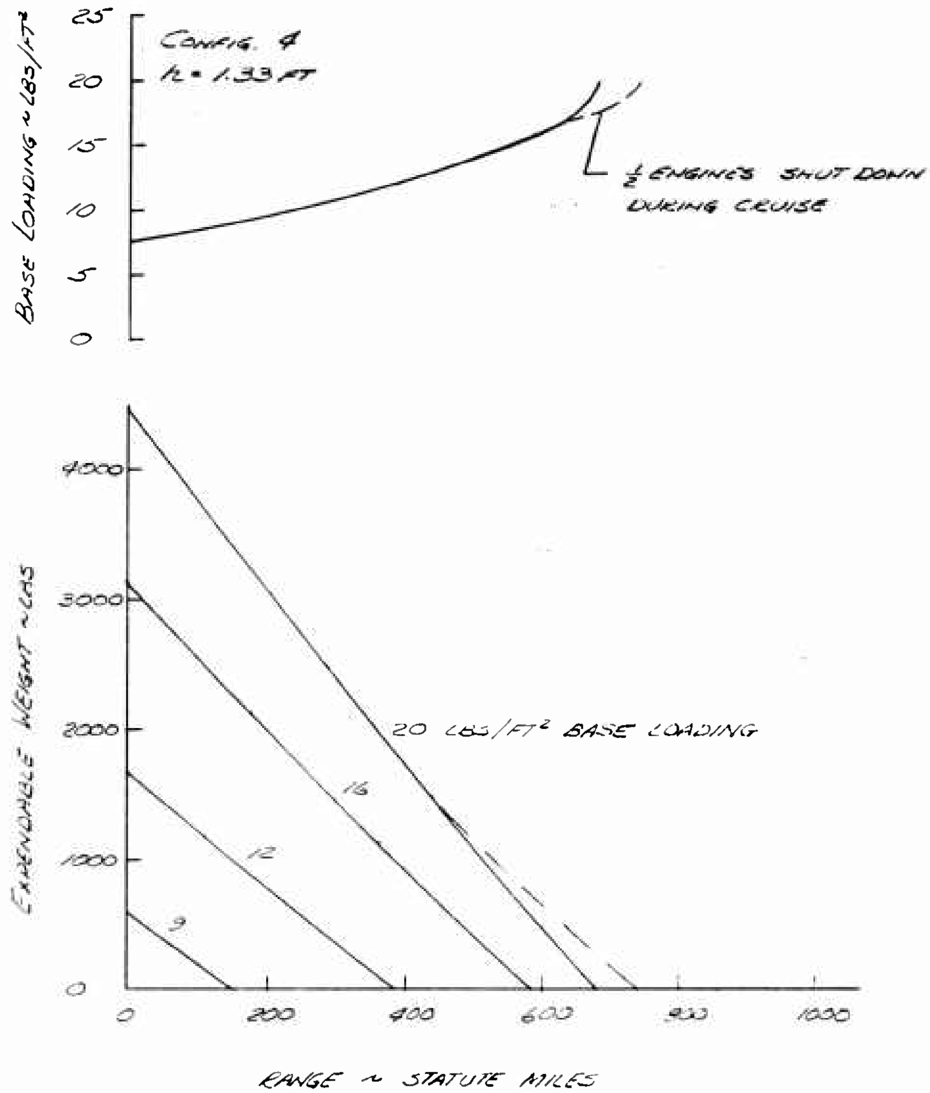


Fig. 15 Expendable Weight/Range - CRV Config. 4

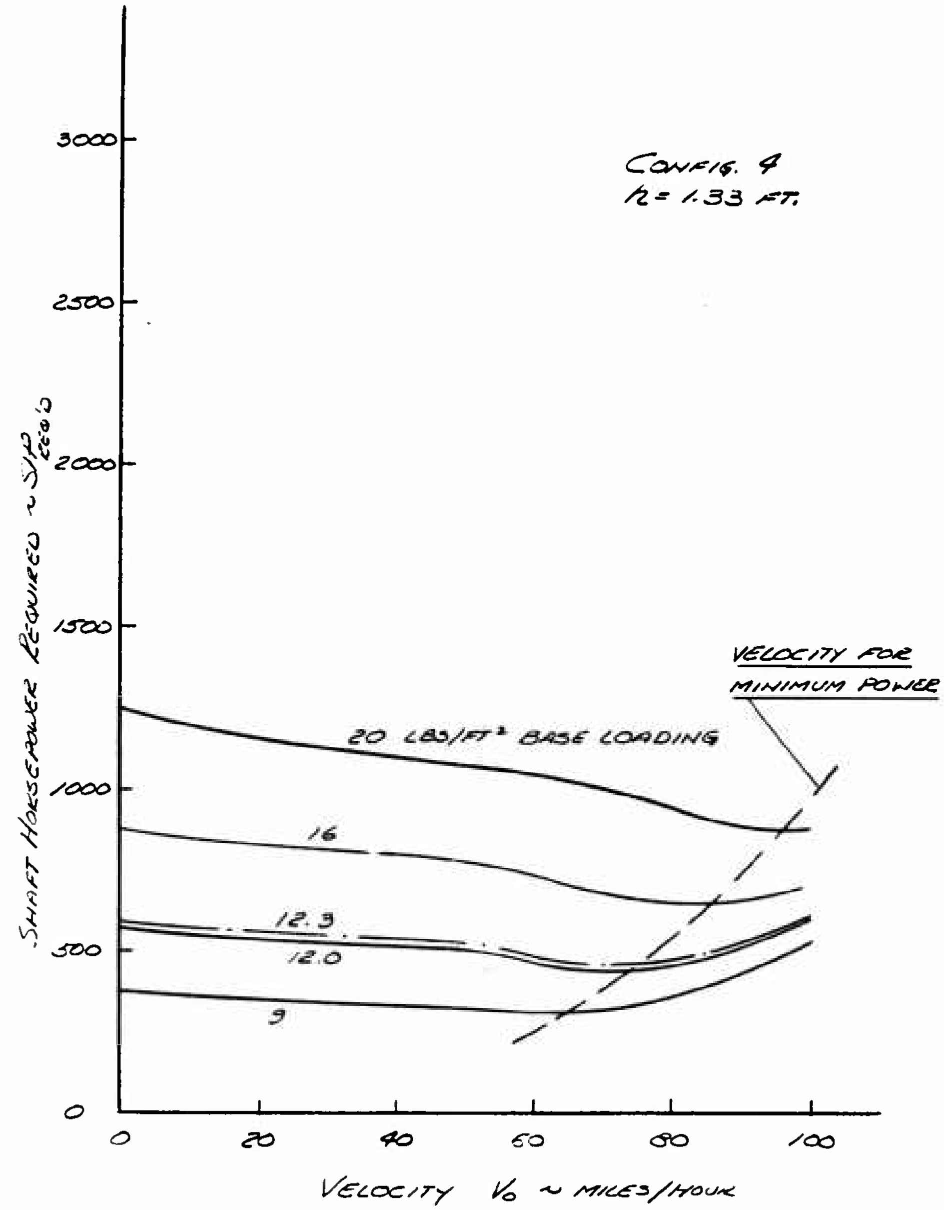


Fig. 16 Shaft Horsepower Required vs. Velocity - CRV Config. 4

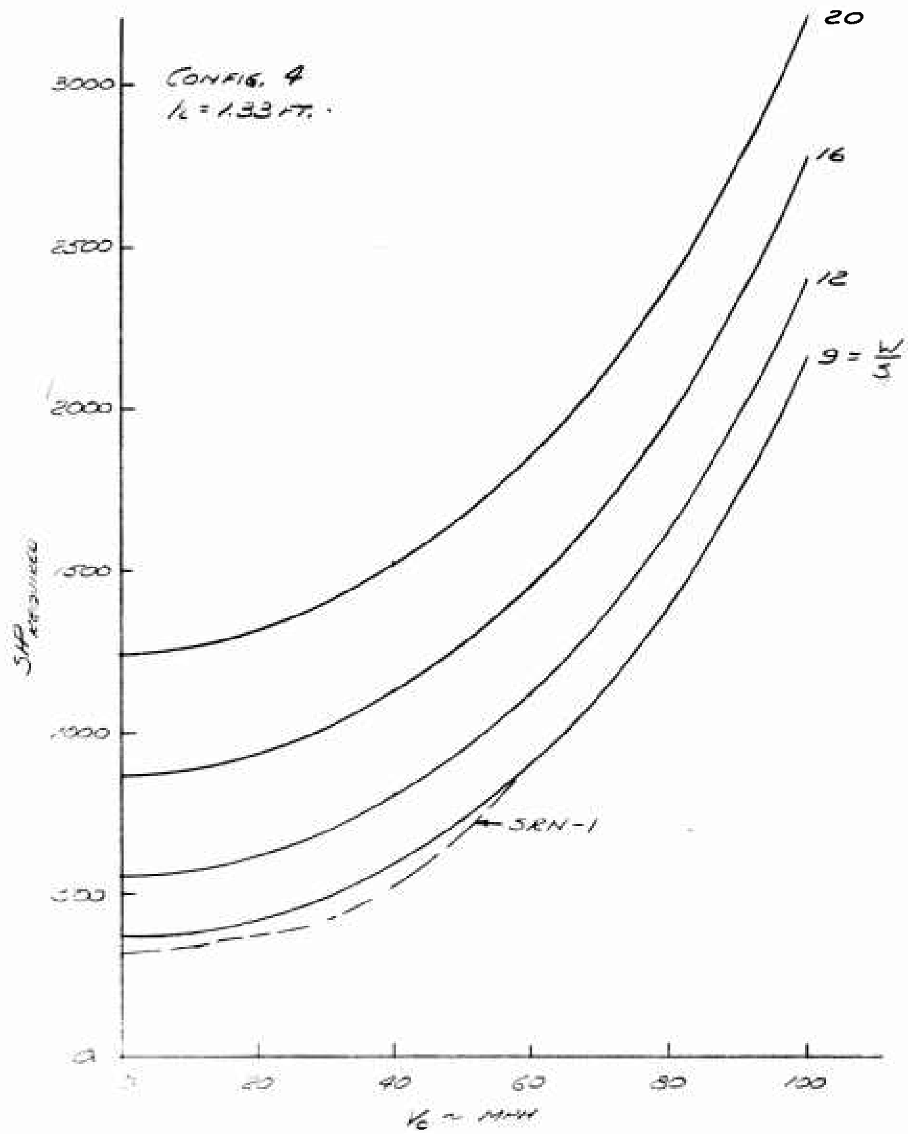


Fig. 17 Shaft Horsepower Required if There Were No Aerodynamic Off-Loading - CRV Config. 4

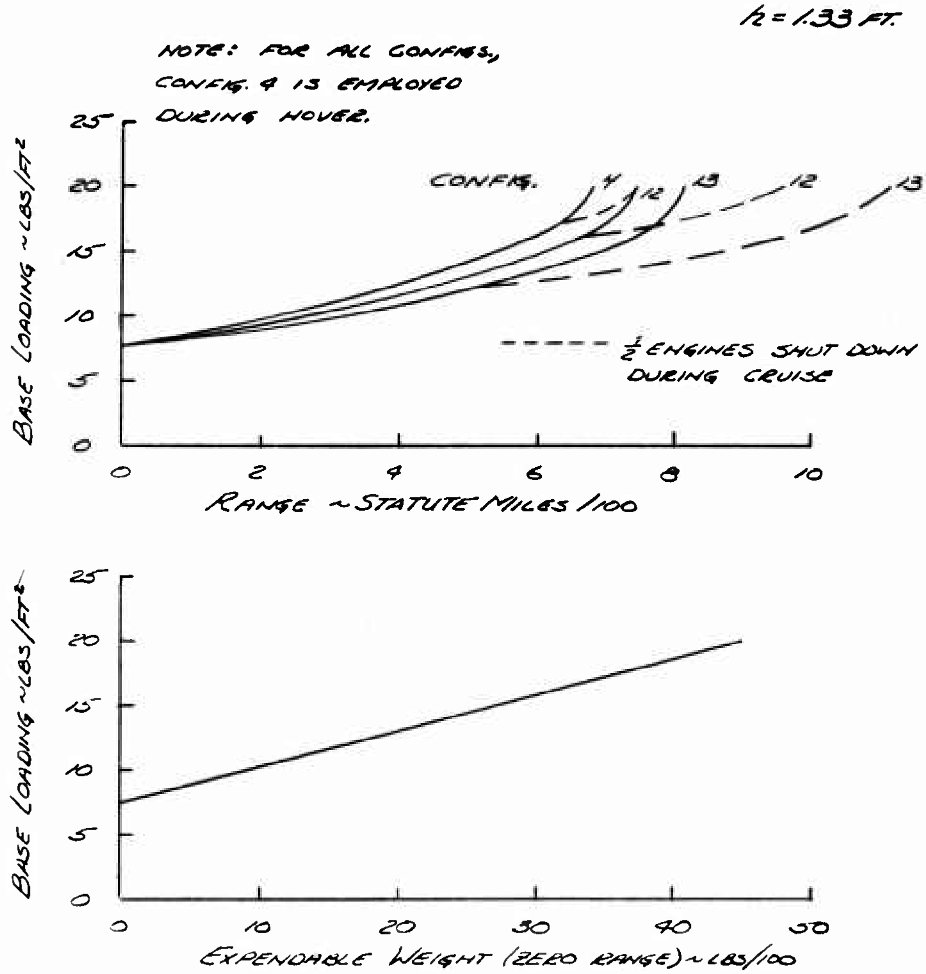


Fig. 18 Effect of Differential Jet Thickness and Angle for Cruise - CRV, h = 1.33 ft.

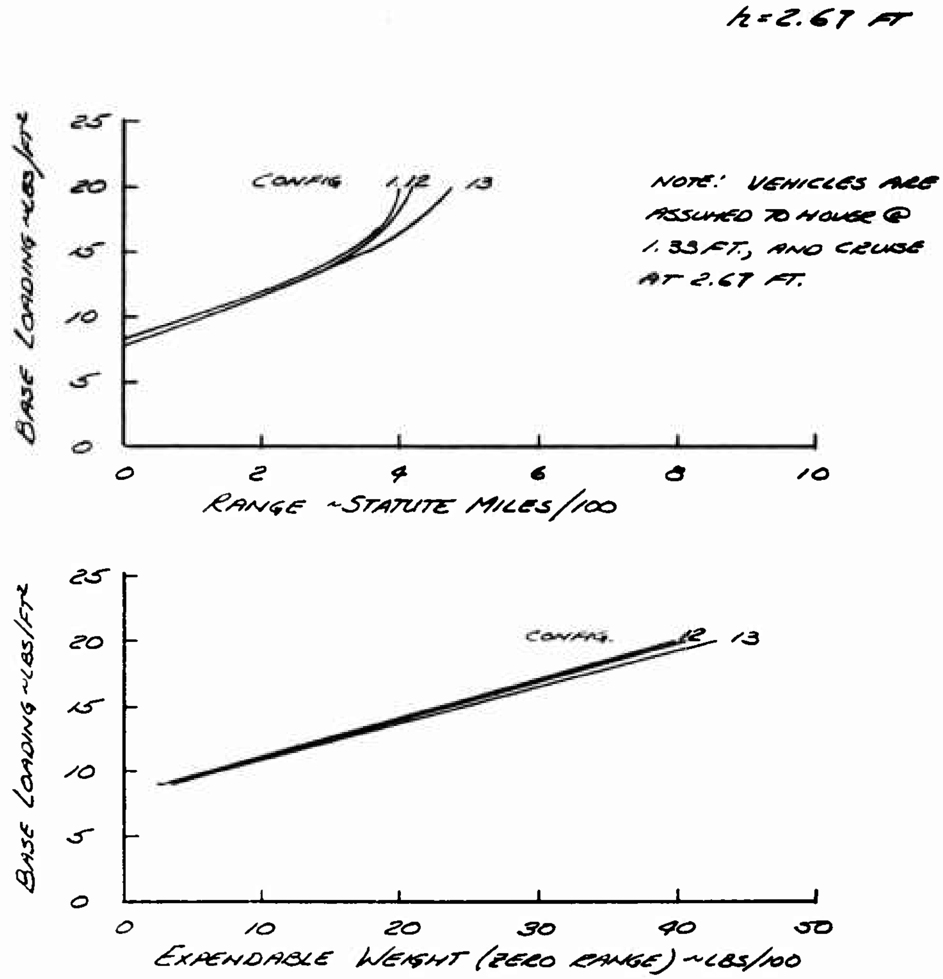


Fig. 19 Effect of Differential Jet Thickness and Angle for Cruise - CRV, h = 2.67 ft.

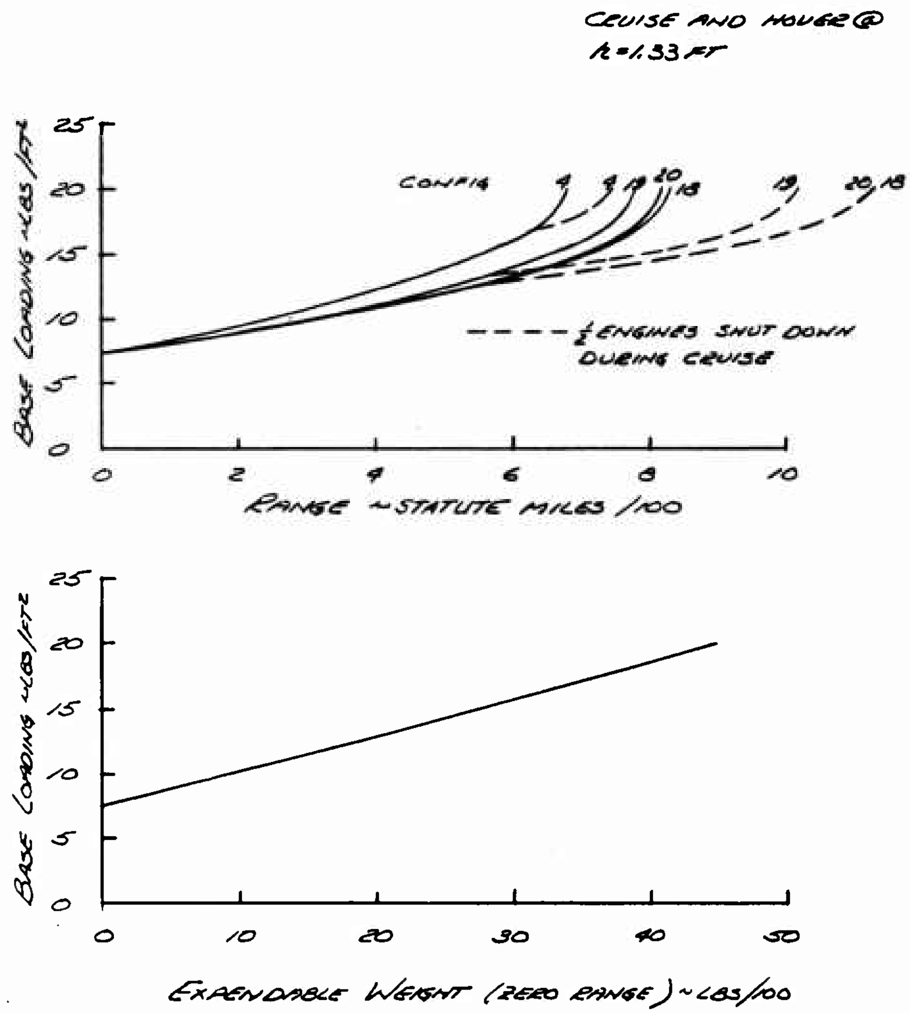


Fig. 20 Effect of Tip Jet Plus Jet Flap During Cruise - CRV, h = 1.33 ft.

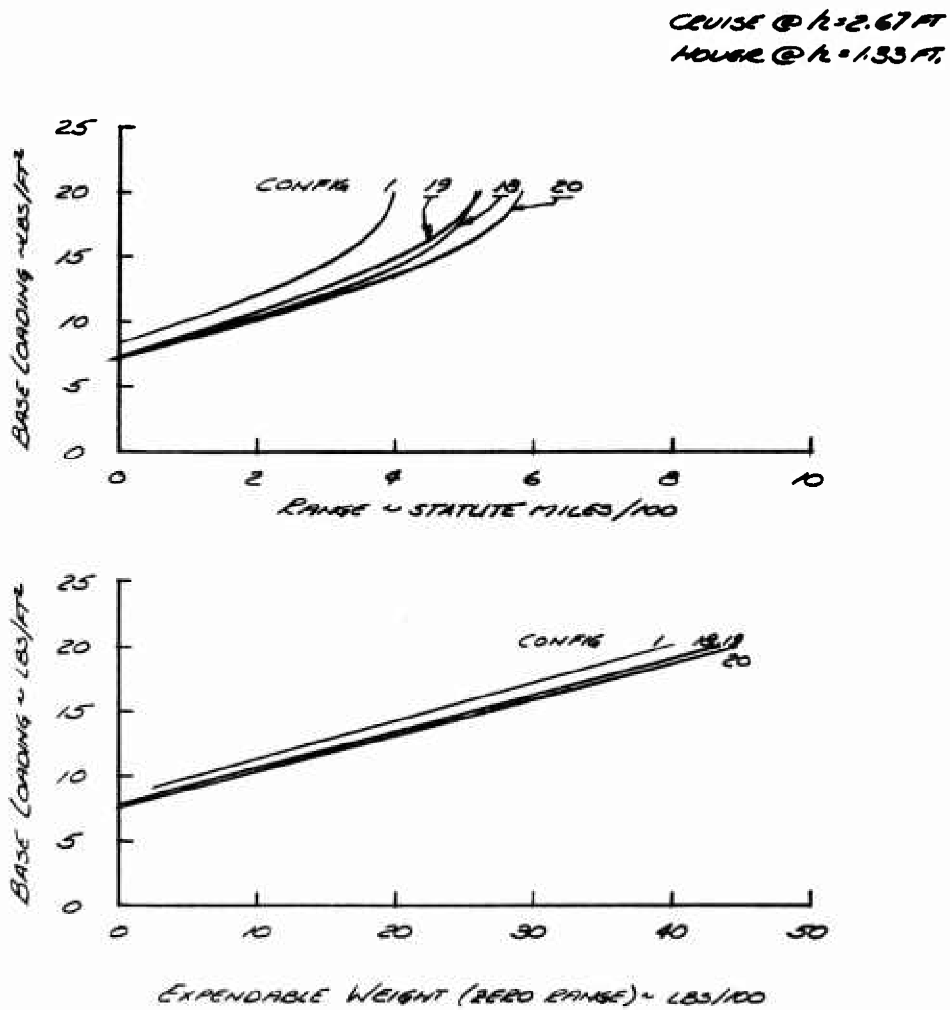


Fig. 21 Effect of Tip Jet Plus Jet Flap During Cruise - CRV, h = 2.67 ft.

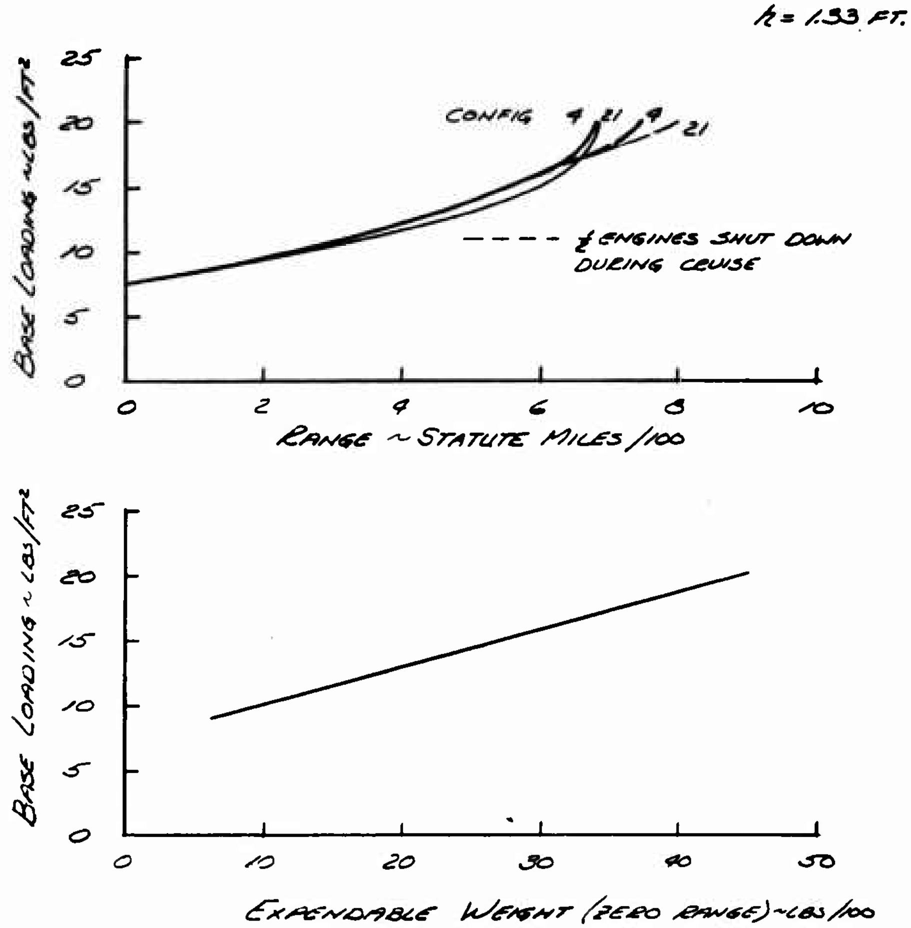


Fig. 22 Effect of Tip Jet Only During Cruise - CRV, h = 1.33 ft.

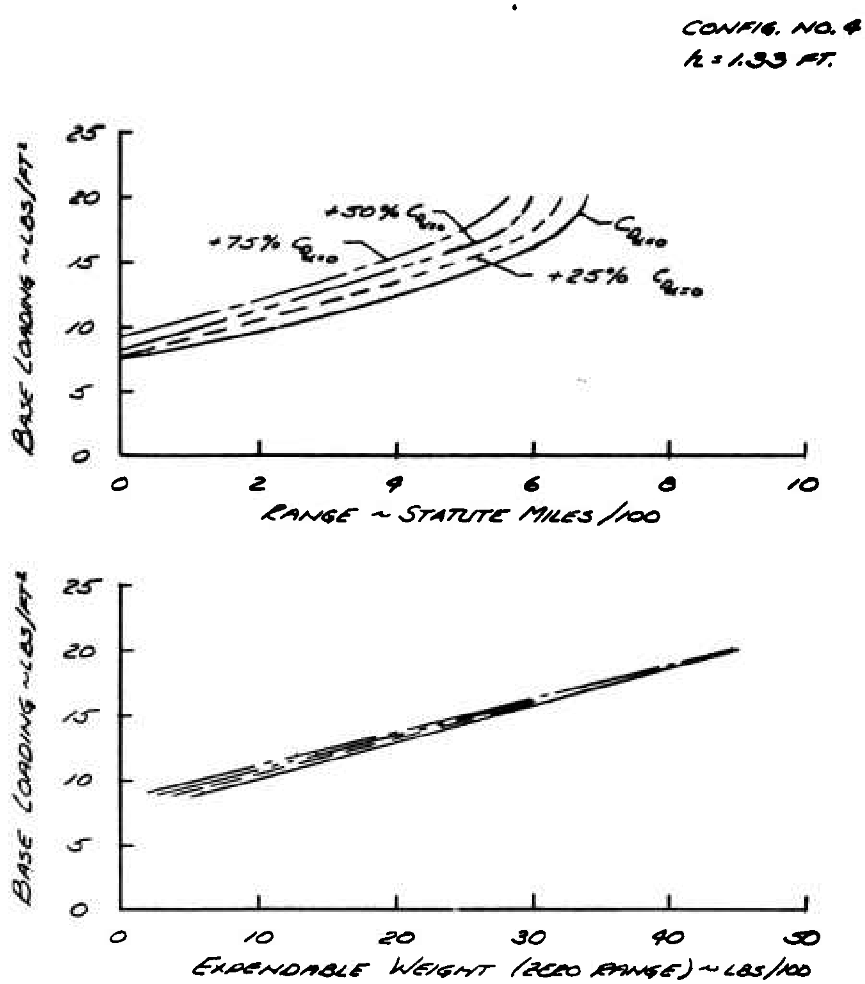


Fig. 23 Effect of Aerodynamic Drag - CRV

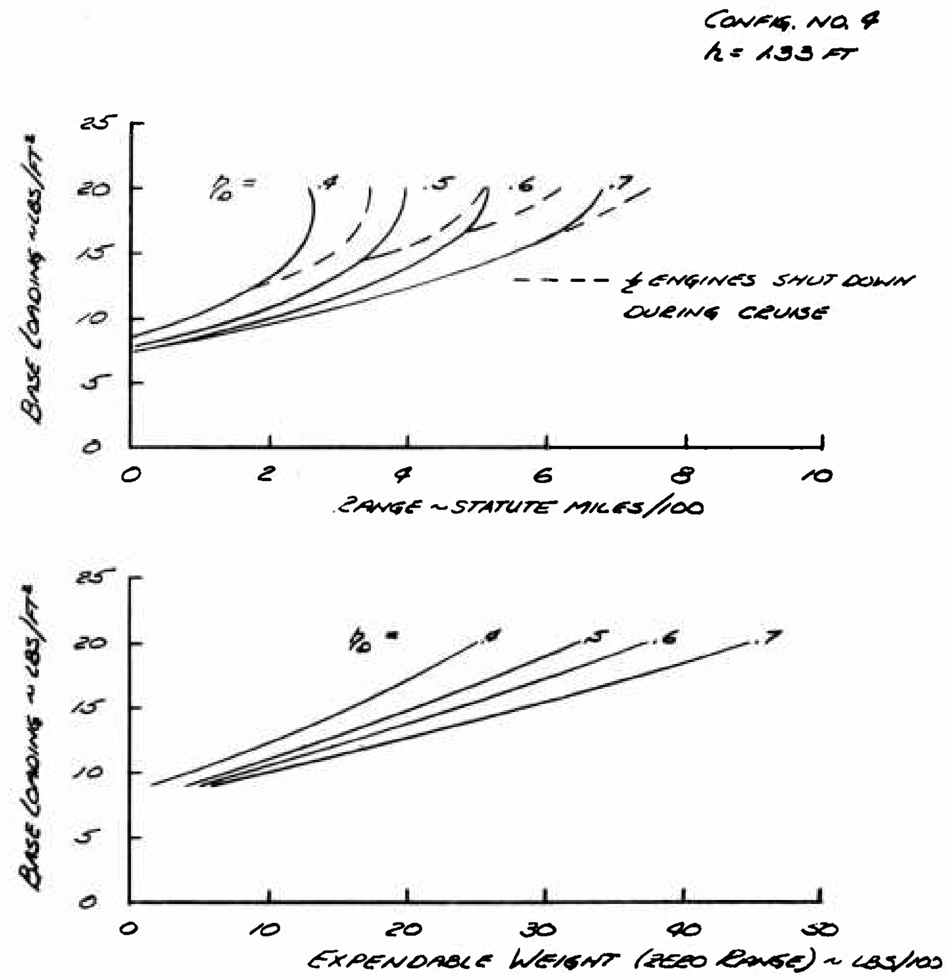


Fig. 24 Effect of Duct Efficiency - CRV

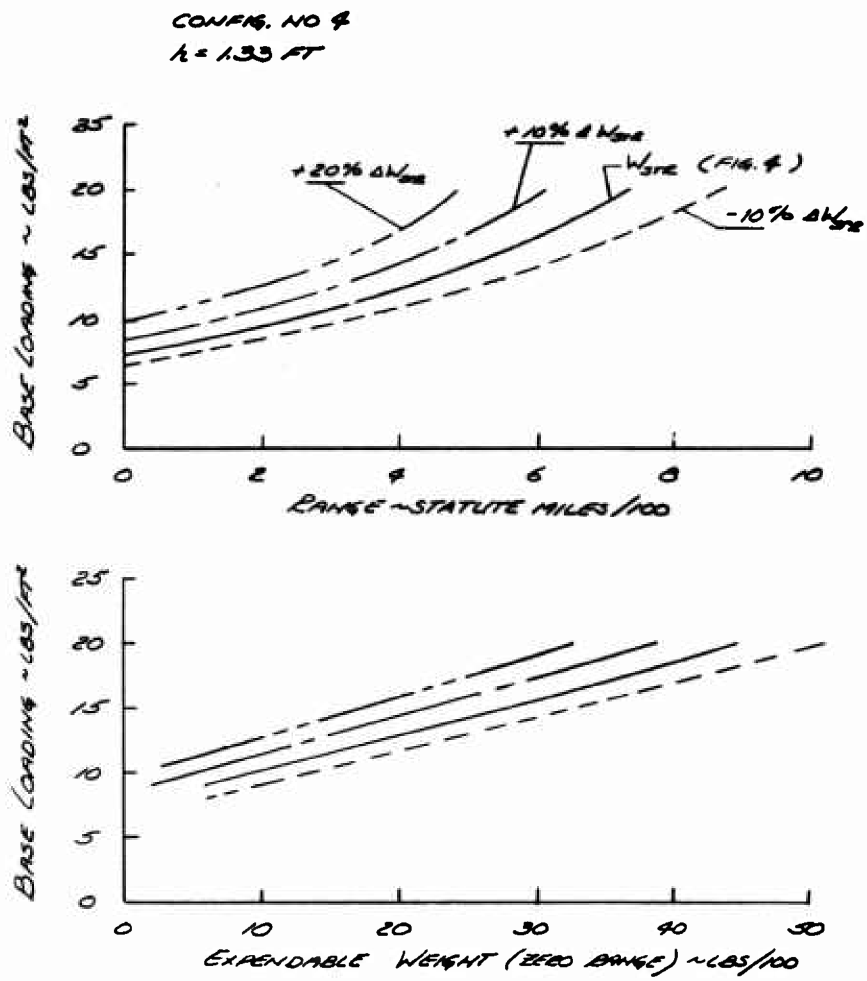


Fig. 25 Effect of Structural Weight - CRV

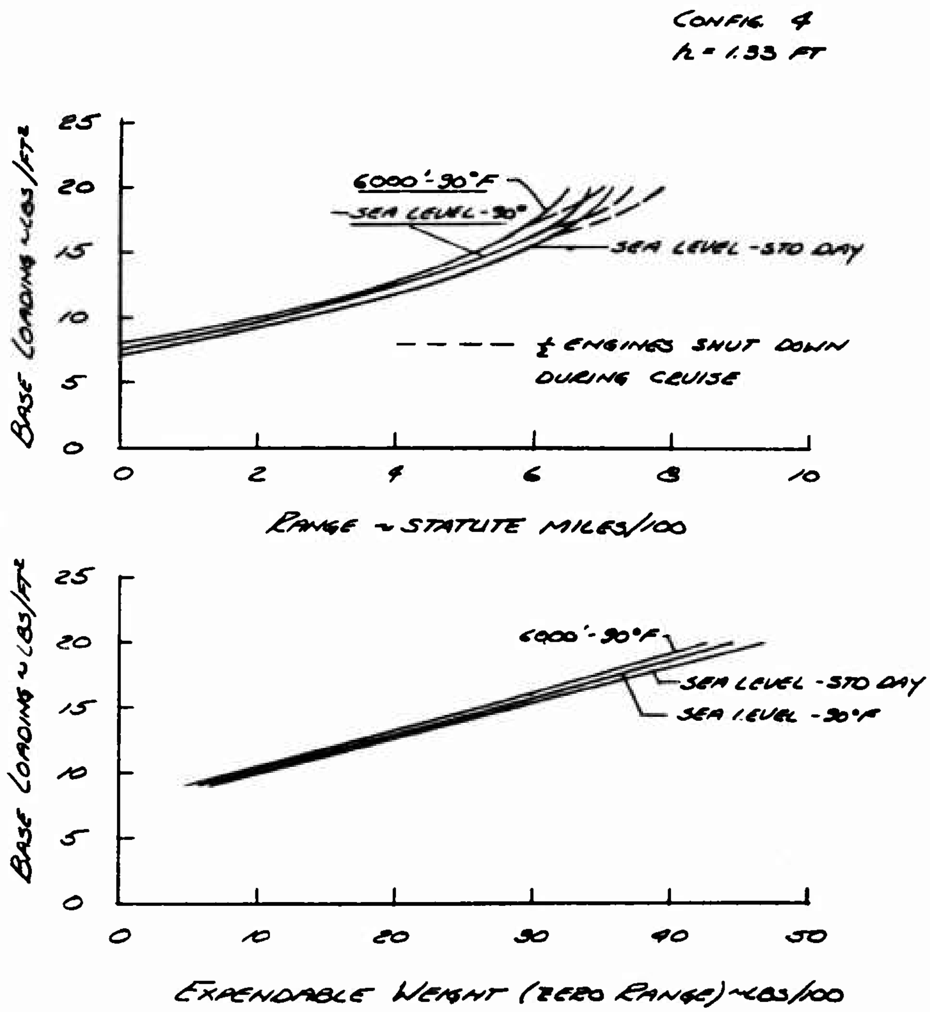


Fig. 26 Effect of Design Temperature - Altitude - CRV

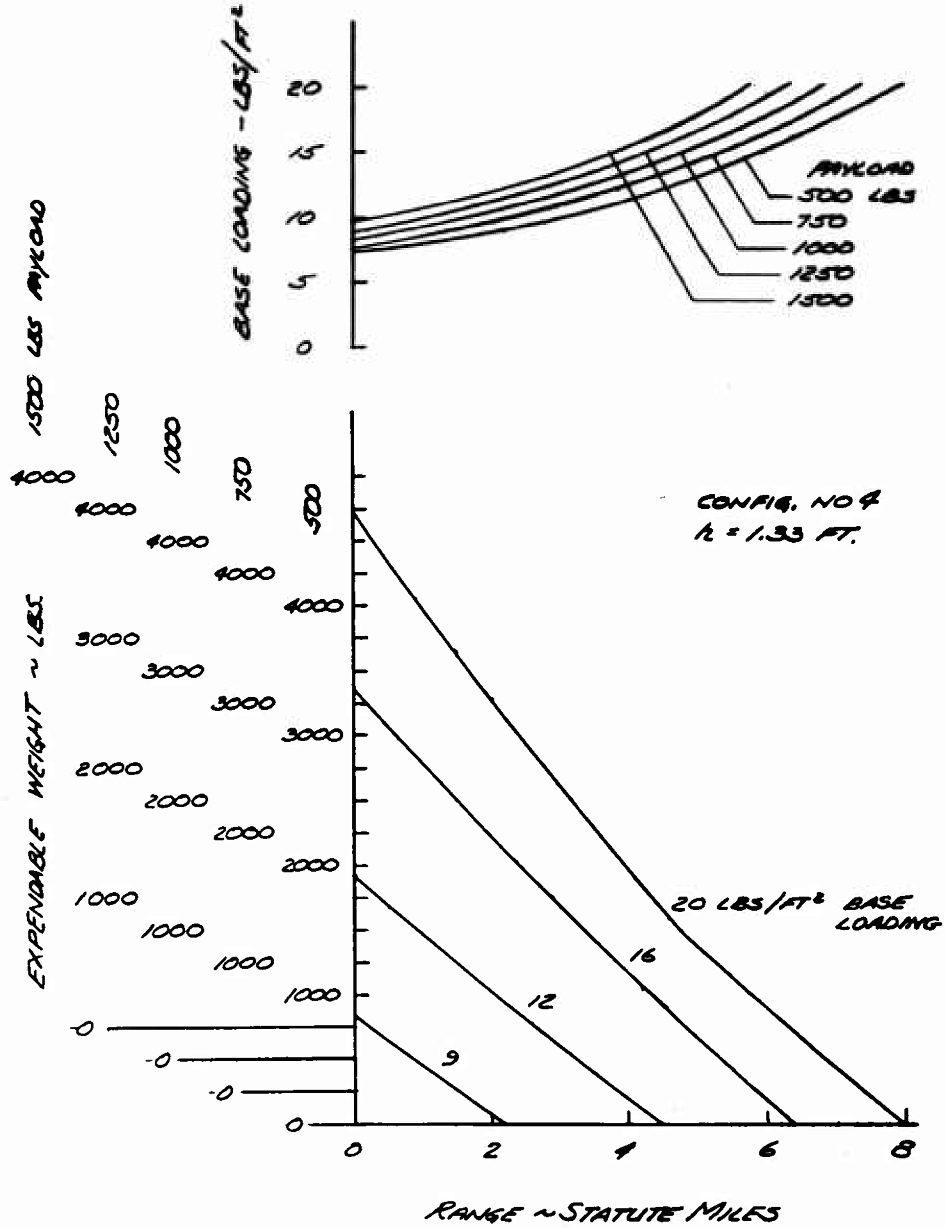


Fig. 27 Effect of Payload Variations - CRV

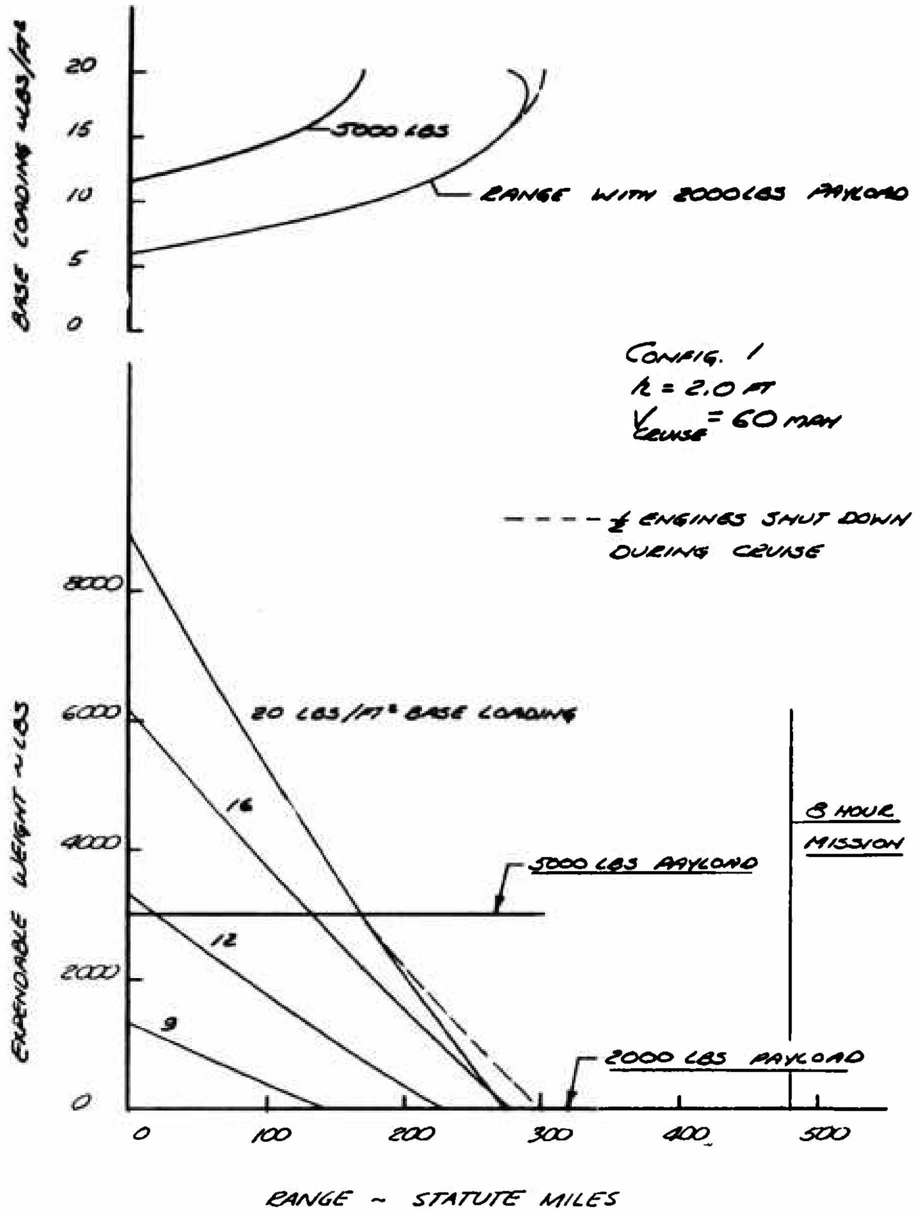


Fig. 28 Expendable Weight/Range - LV Config. 1

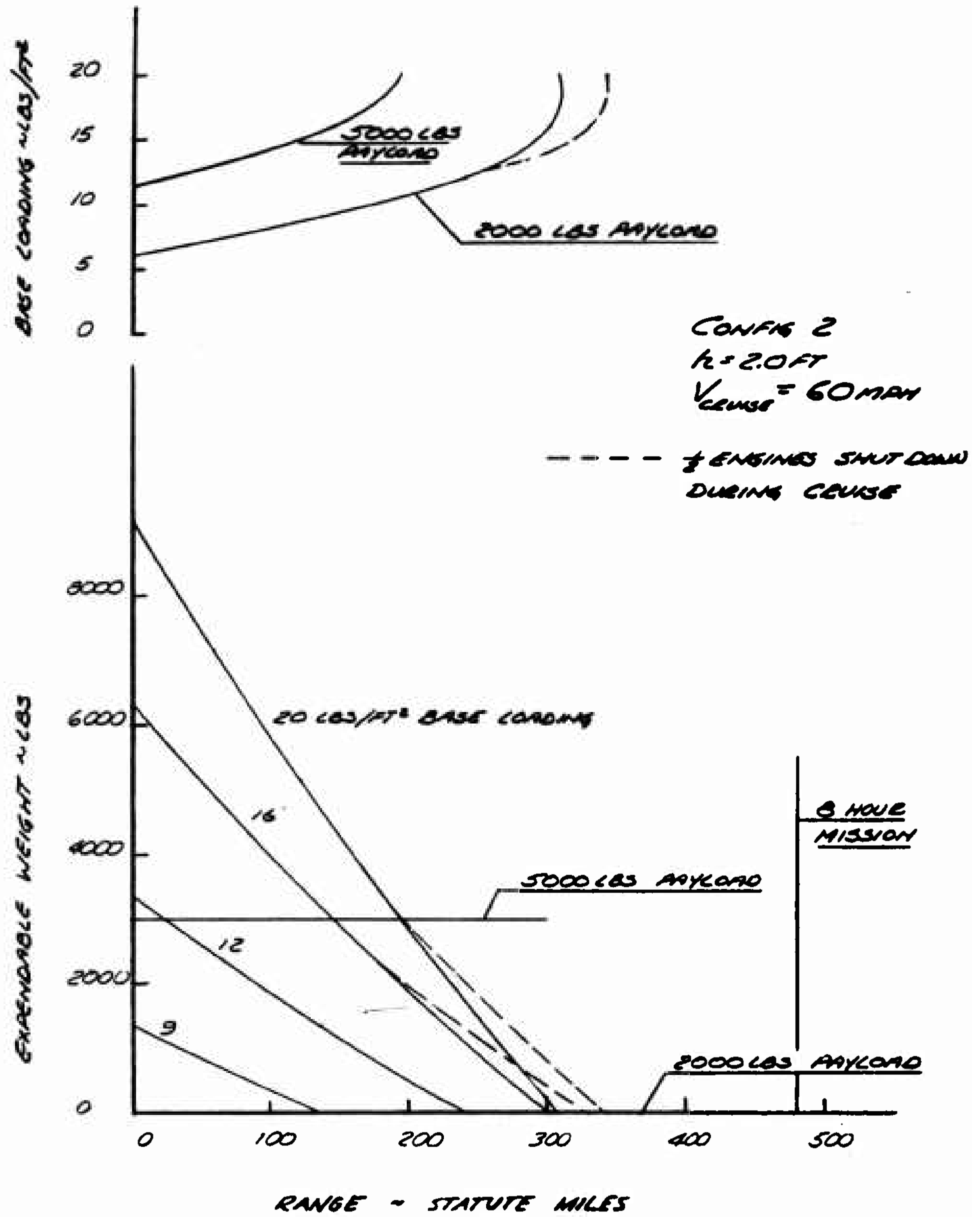


Fig. 29 Expendable Weight/Range - LV Config. 2

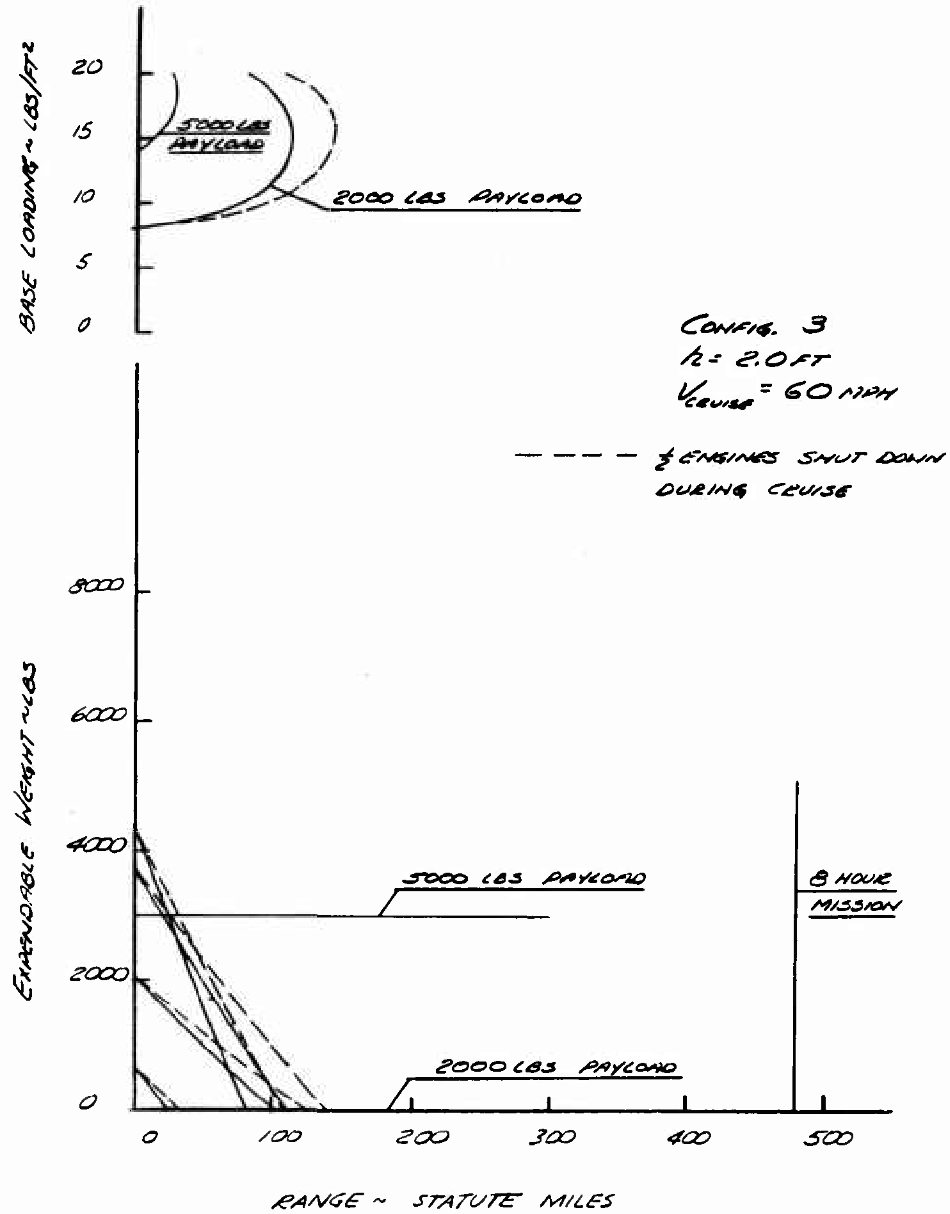


Fig. 30 Expendable Weight/Range - LV Config. 3

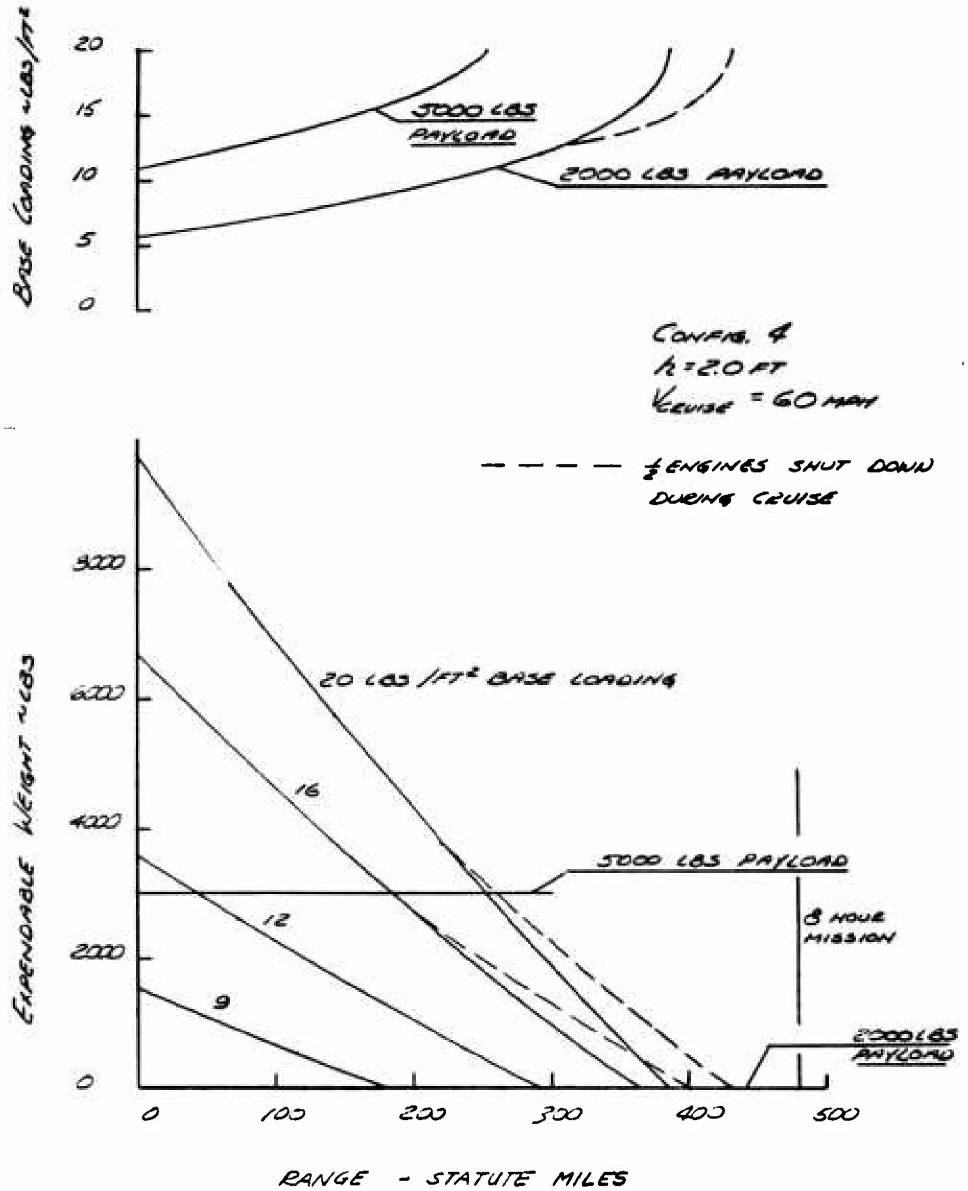


Fig. 31 Expendable Weight/Range - LV Config. 4

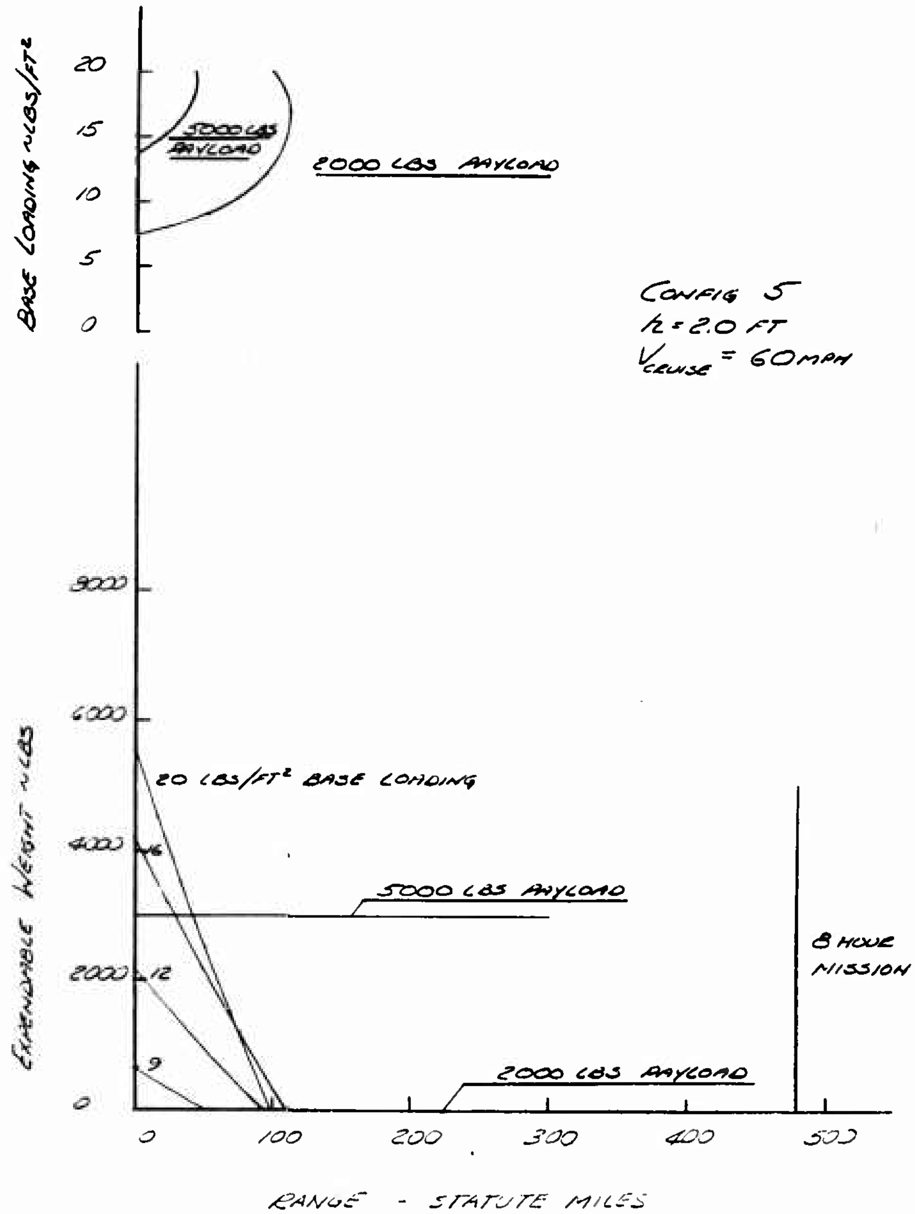


Fig. 32 Expendable Weight/Range - LV Config. 5

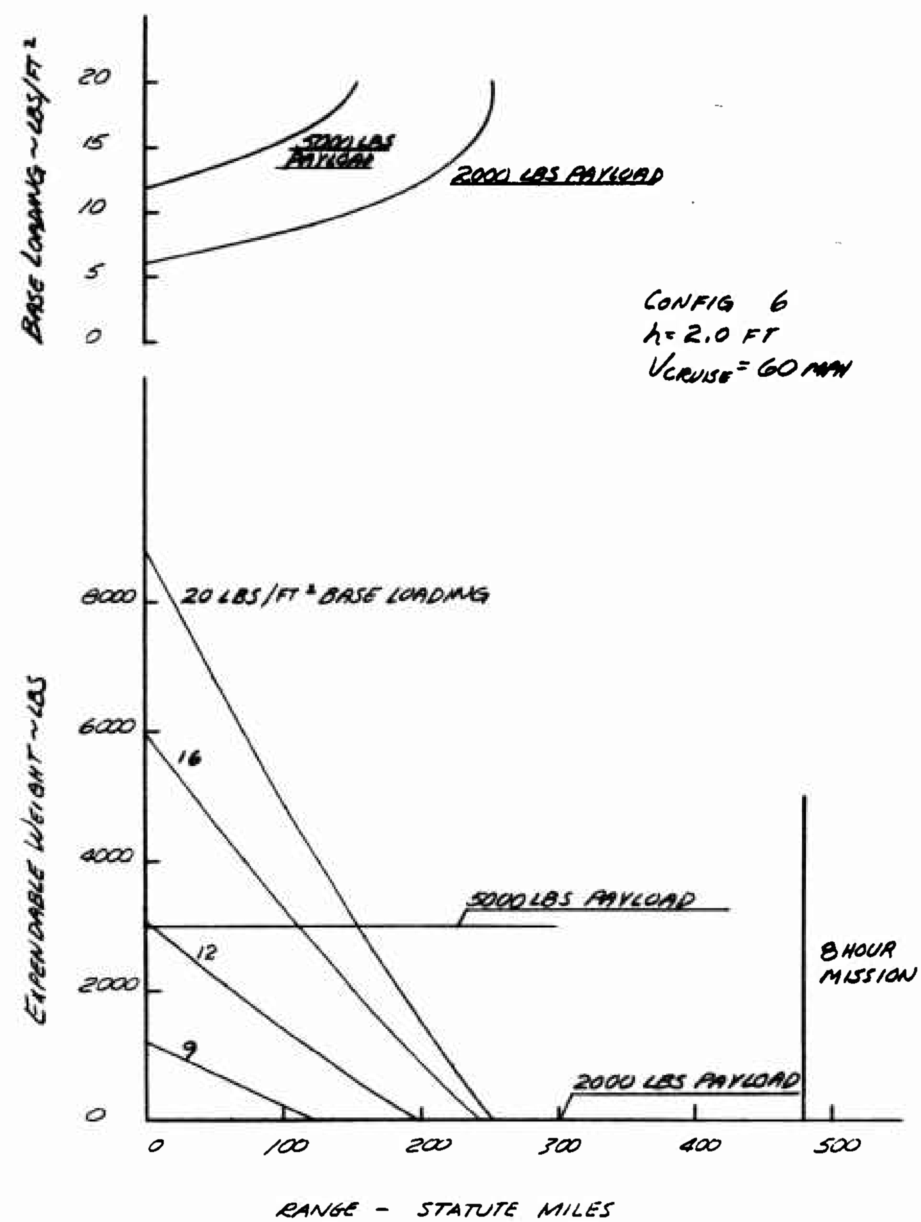


Fig. 33 Expendable Weight/Range - LV Config. 6

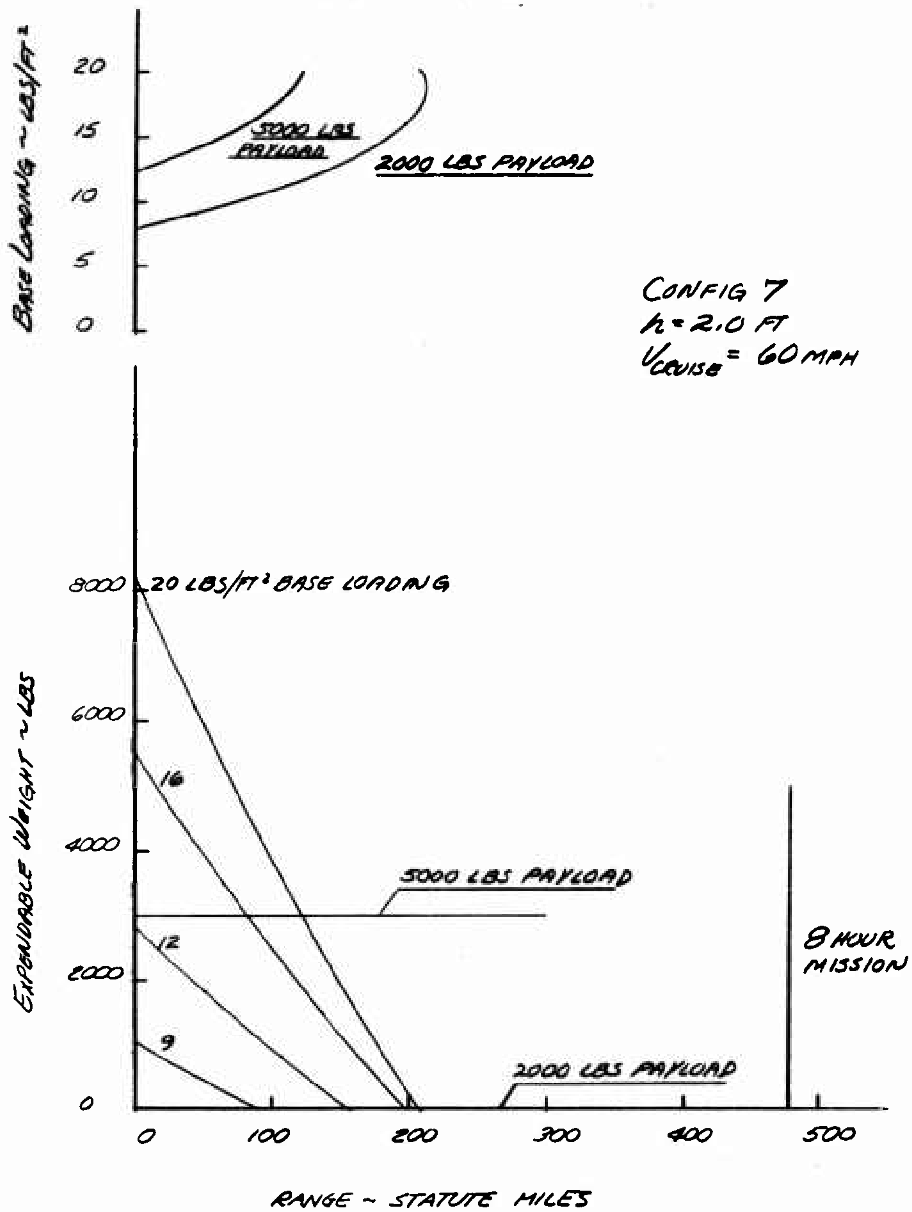


Fig. 34 Expendable Weight/Range - LV Config. 7

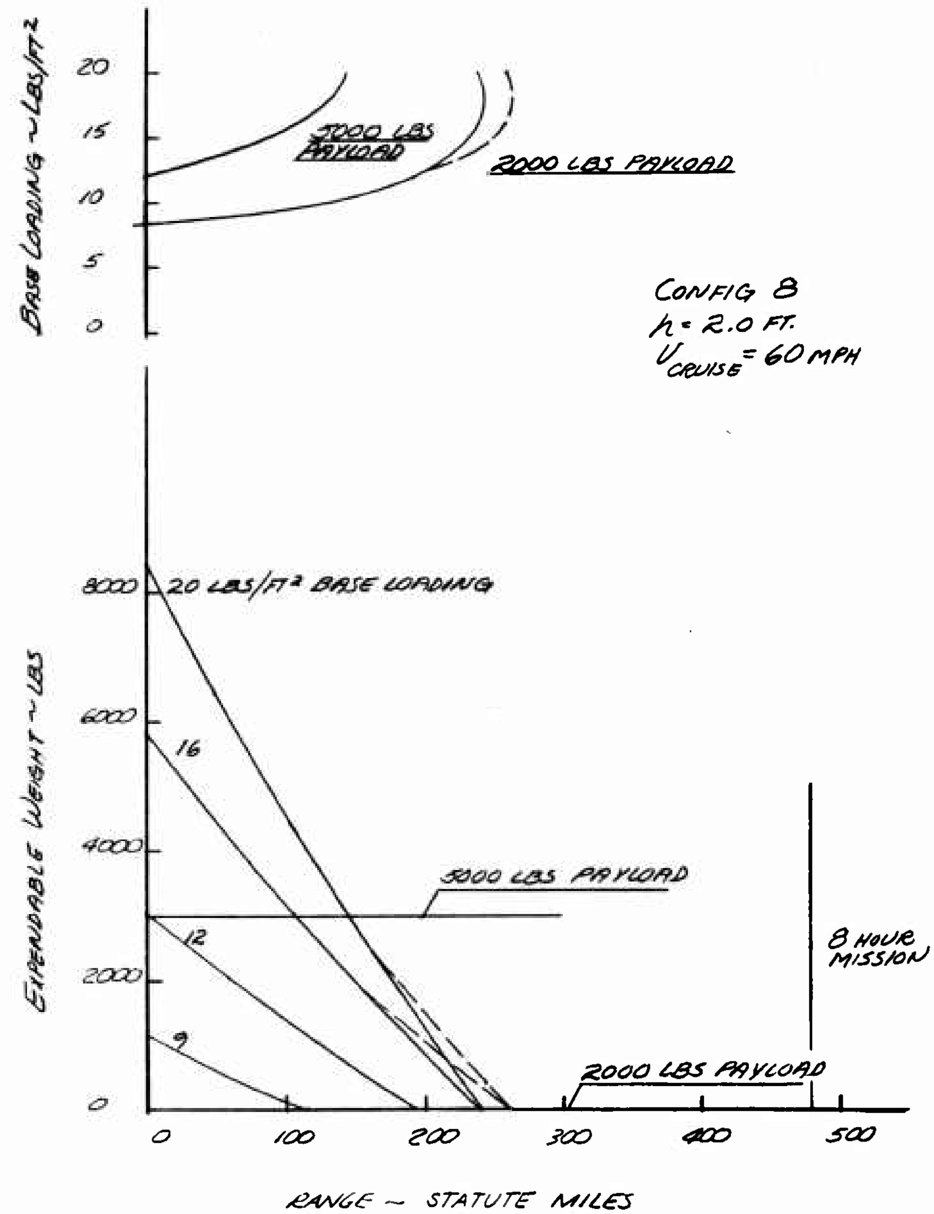


Fig. 35 Expendable Weight/Range - LV Config. 8

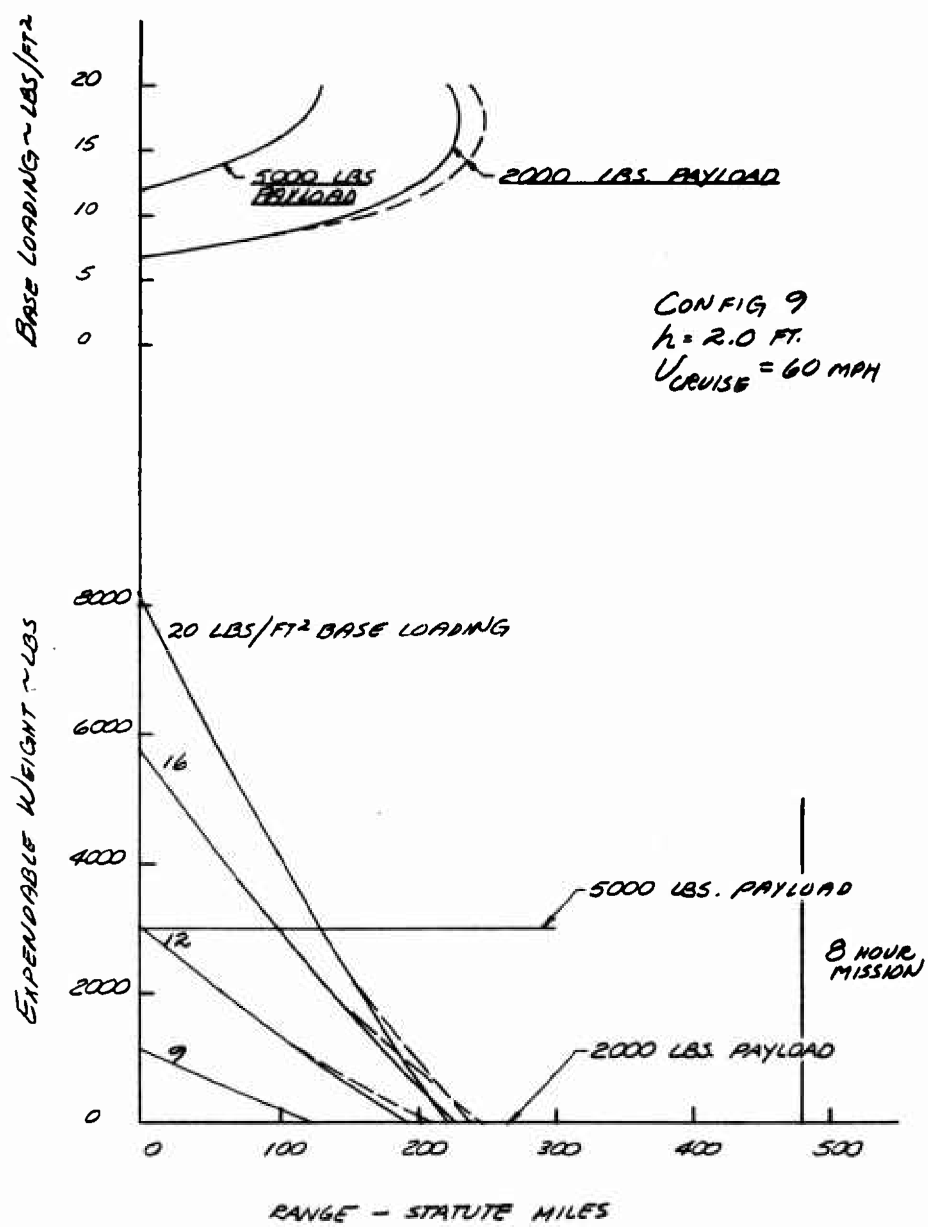


Fig. 36 Expendable Weight/Range - LV Config. 9

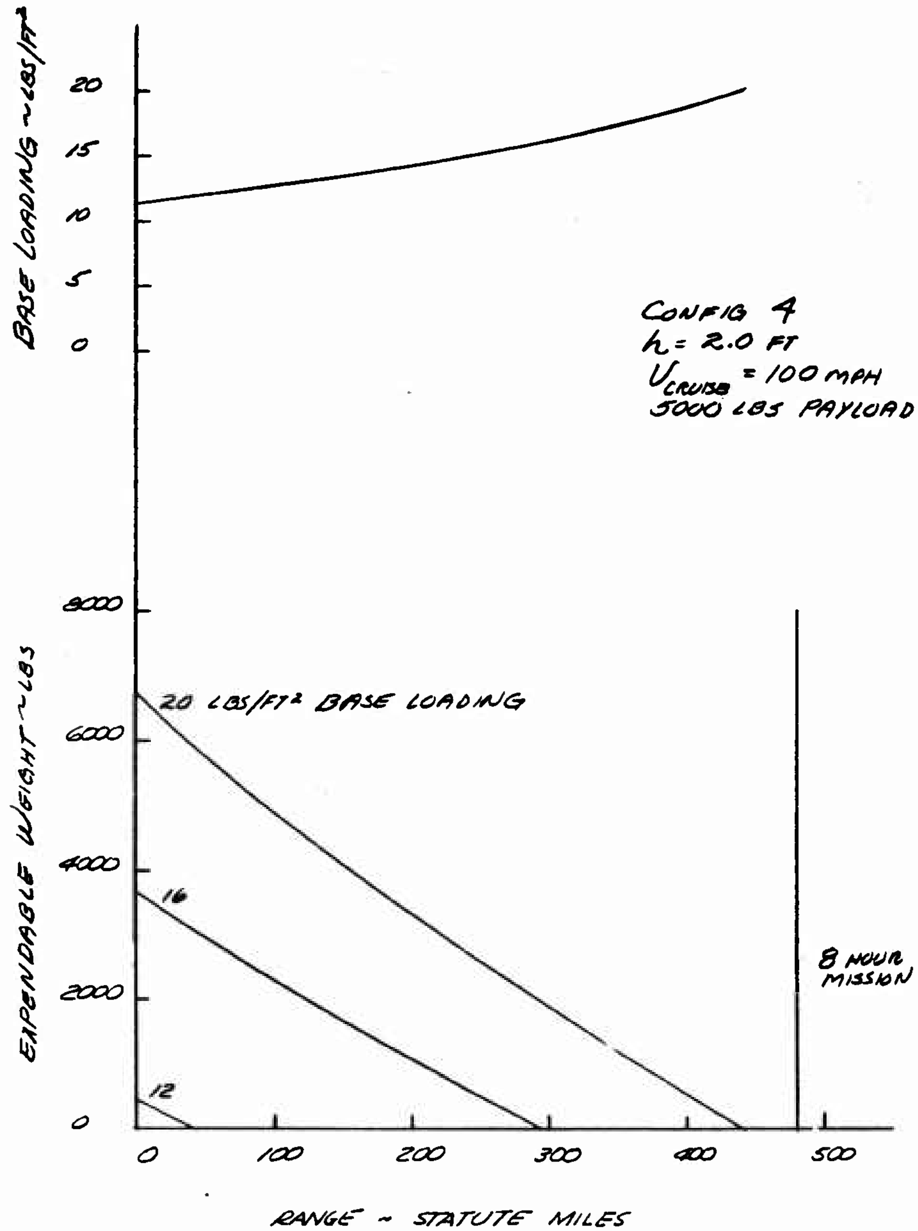


Fig. 37 Expendable Weight/Range - LV Config. 4, Cruise at 100 mph

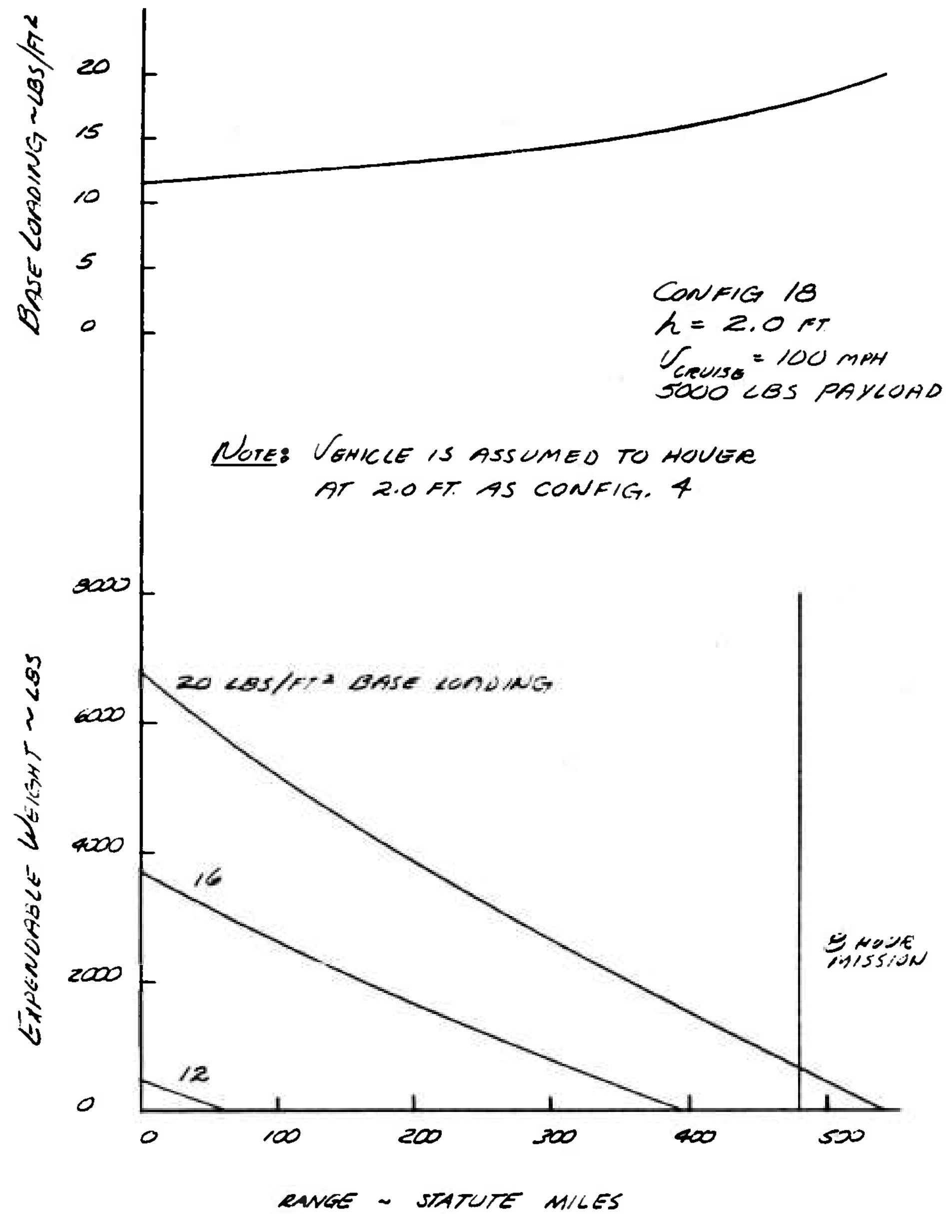


Fig. 38 Expendable Weight/Range - LV Config. 18, Cruise at 100 mph, h = 2.0 ft.

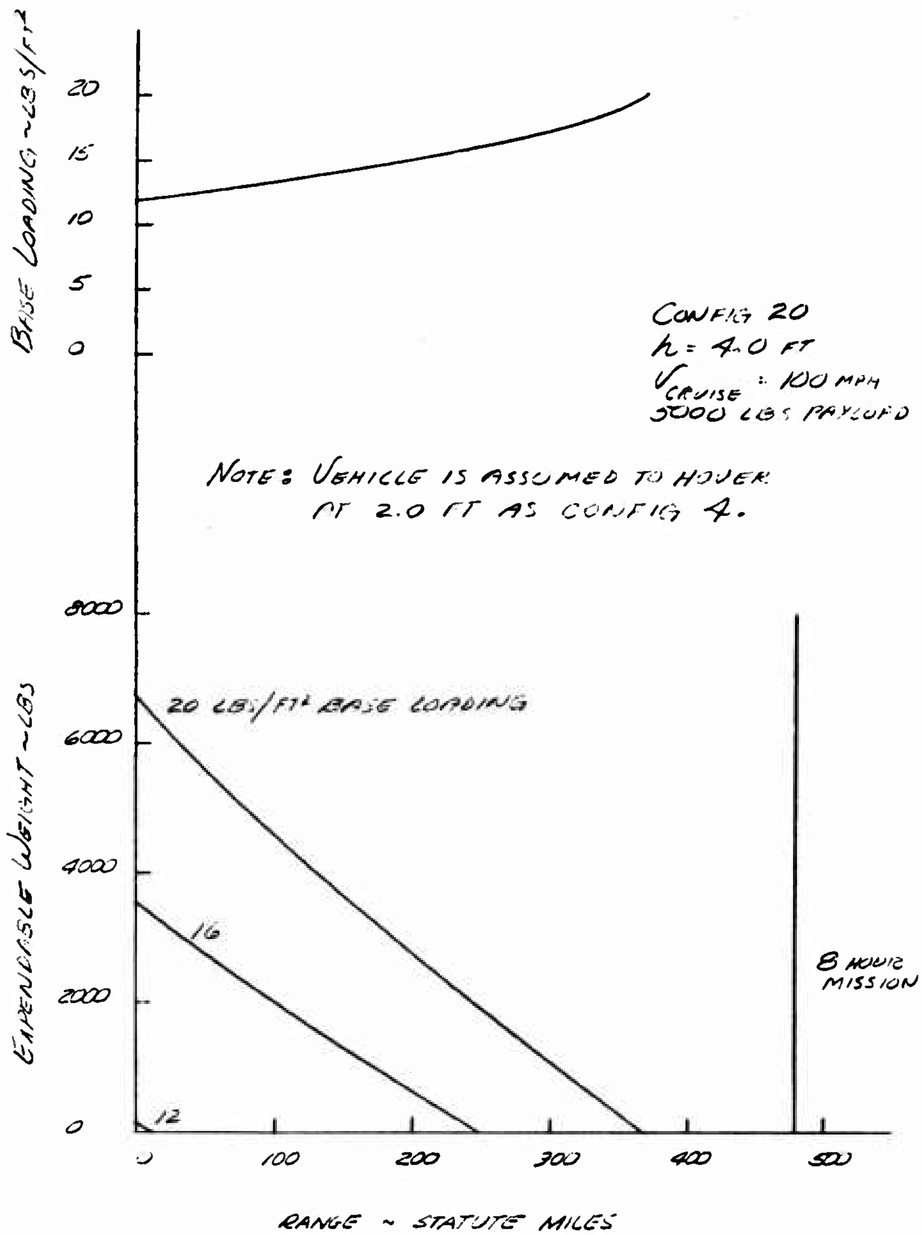


Fig. 39 Expendable Weight/Range - LV Config. 20, Cruise at 100 mph, h = 4.0 ft.

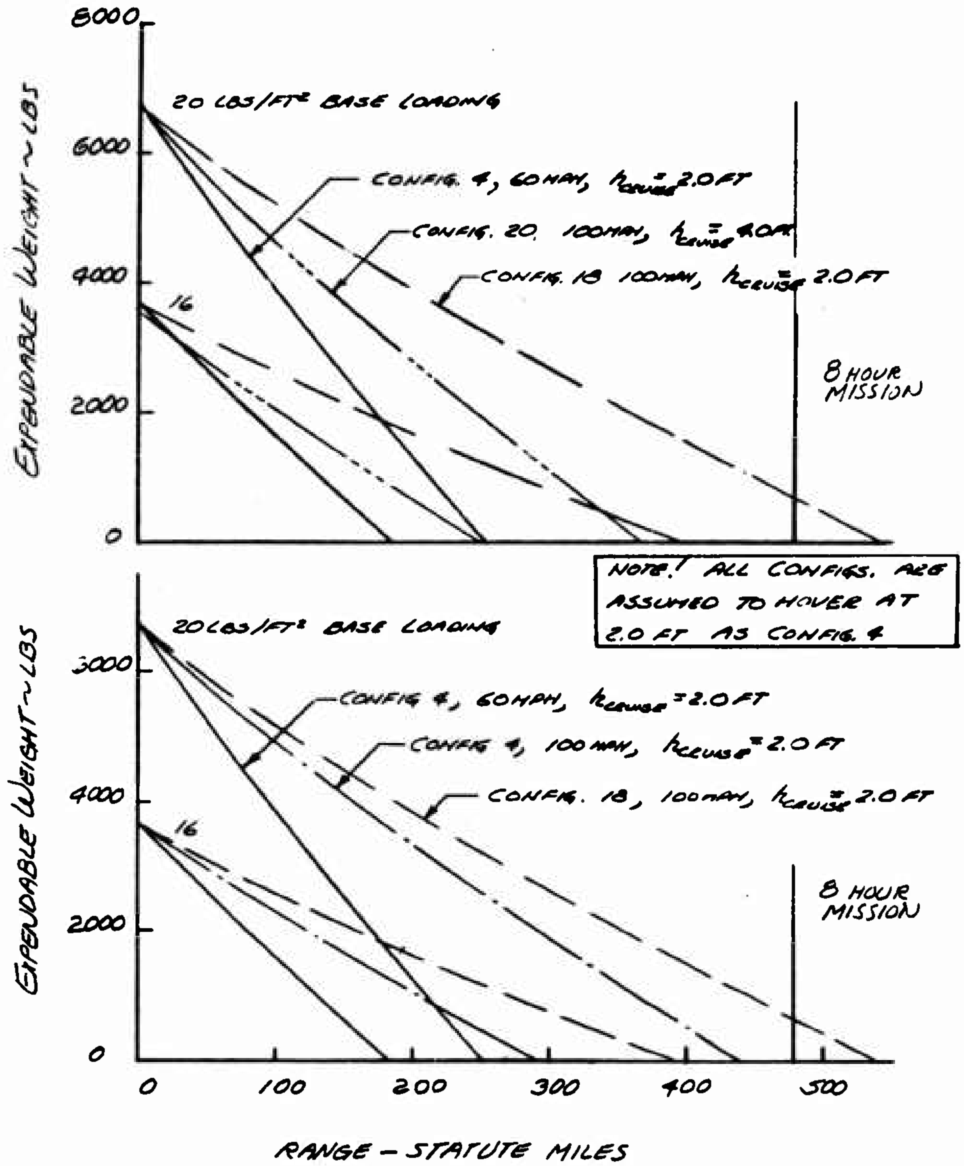


Fig. 40 Expendable Weight/Range - LV.Effect of Increased Speed on Range, Payload and/or Height

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Air Univ Lib	1
ASD(ASRMPT)	1
CNO	1
CNR	3
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ACRD(OW), DN	1
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TCREC Technical Report 62-51, June 1962, 87pp. (Contract DA 44-177-TC-708) Task 9R99-01-005-03, Unclassified Report

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Multiple engine installations also appear to be highly desirable. Because of the dissimilar power requirements between hover and aerodynamically off-loaded cruise at a given height, range at this height can be extended by shutting down some portion of the installed engines (turboprop or turboshaft) and operating the remainder at higher, more efficient, power settings.

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